Energy Dependence of Dielectron Production in Au+Au Collisions at RHIC

Jie Zhao

Aug.14 2014

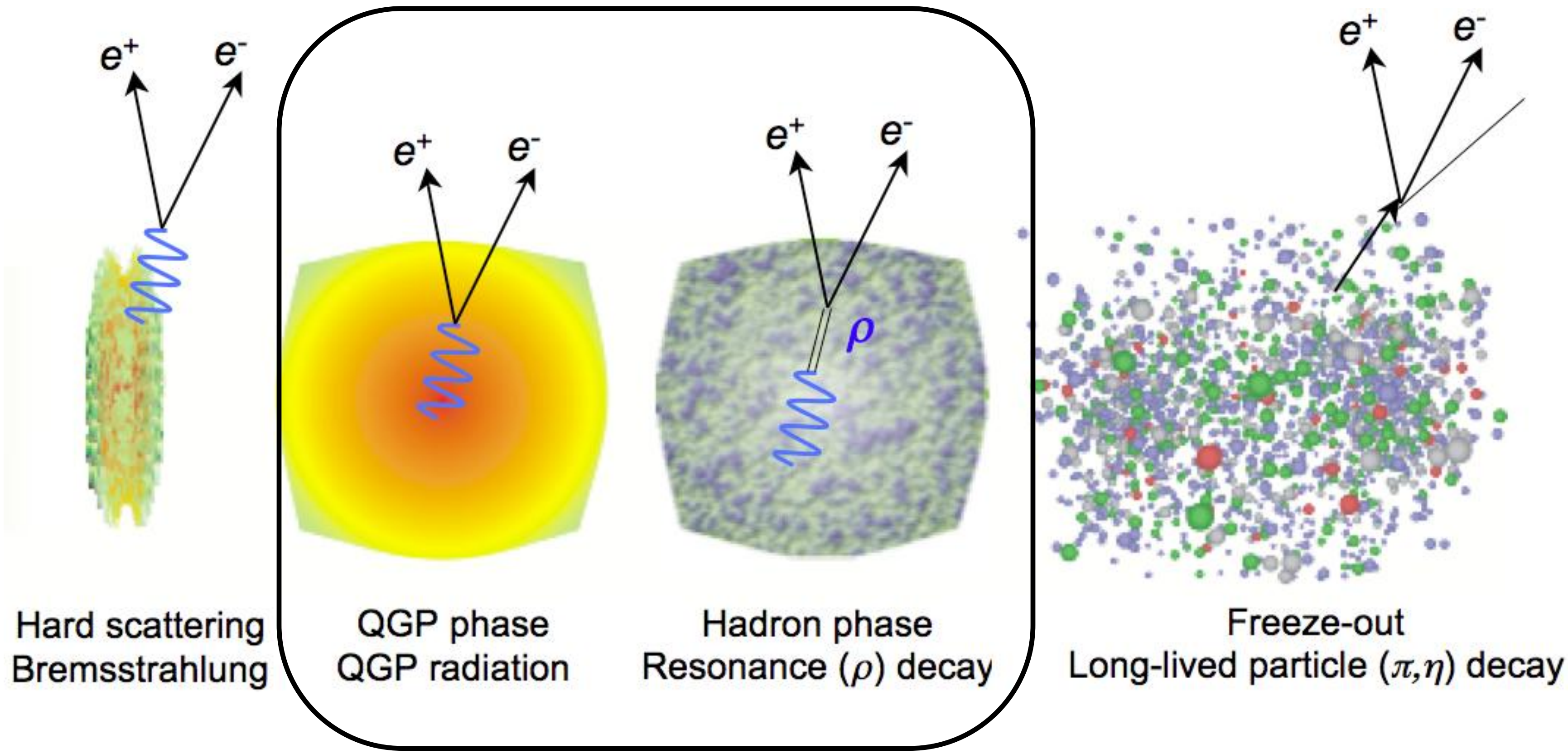
Central China Normal University, Wuhan

Many thanks to:
Joey Butterworth, Xiangli Cui, Xin Dong, Frank Geurts, Yu-gang Ma, Yi Guo, Bingchu Huang, Patrick Huck, Kurt Jung, Olena Linnyk, Mustafa Mustafa, Ralf Rapp, Lijuan Ruan, Qun Wang, Wei Xie, Hao-jie Xu, Zhangbu Xu, Yifei Zhang

Outline

- **Motivation**
- **Results from 200GeV Au+Au Collisions**
- **Results from RHIC-Beam Energy Scan**
- **Summary and Outlook**

A Penetrating Probe to Medium

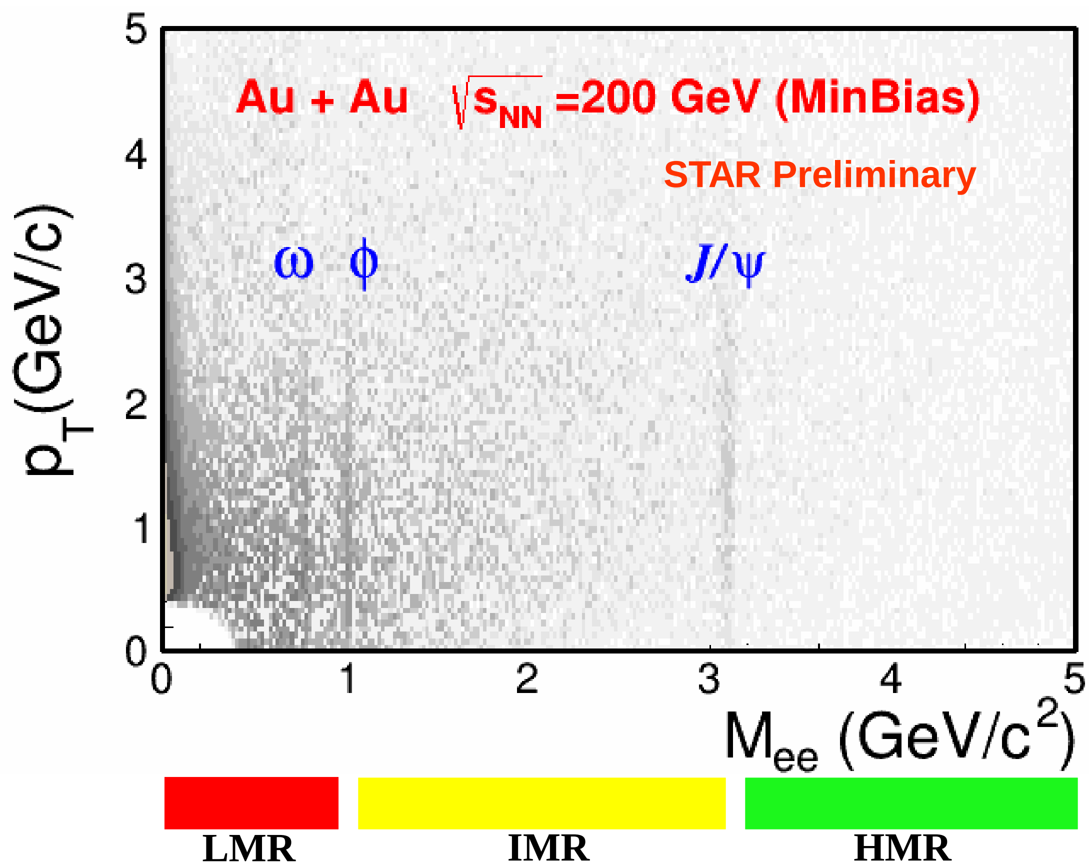


Advantages: EM probe / penetrating – not suffer strong interactions
(p_T, M) – additional mass dimension, sensitive to different dynamics

Challenges: Production rate is rare, over many background sources
integral over time, sensitive to system evolution

Motivation

STAR QM11



Provide two dimensions (mass vs p_T)

✓ ***mapping to the collisions dynamics***

✓ ***higher mass, earlier production***

➢ **Low mass region (LMR):**

in-medium modifications of vector mesons

chiral symmetry restoration

➢ **Intermediate mass region (IMR):**

thermal radiation expected to have significant contribution

dominated by charm in p+p, but the contribution is expected to be modified in Au+Au

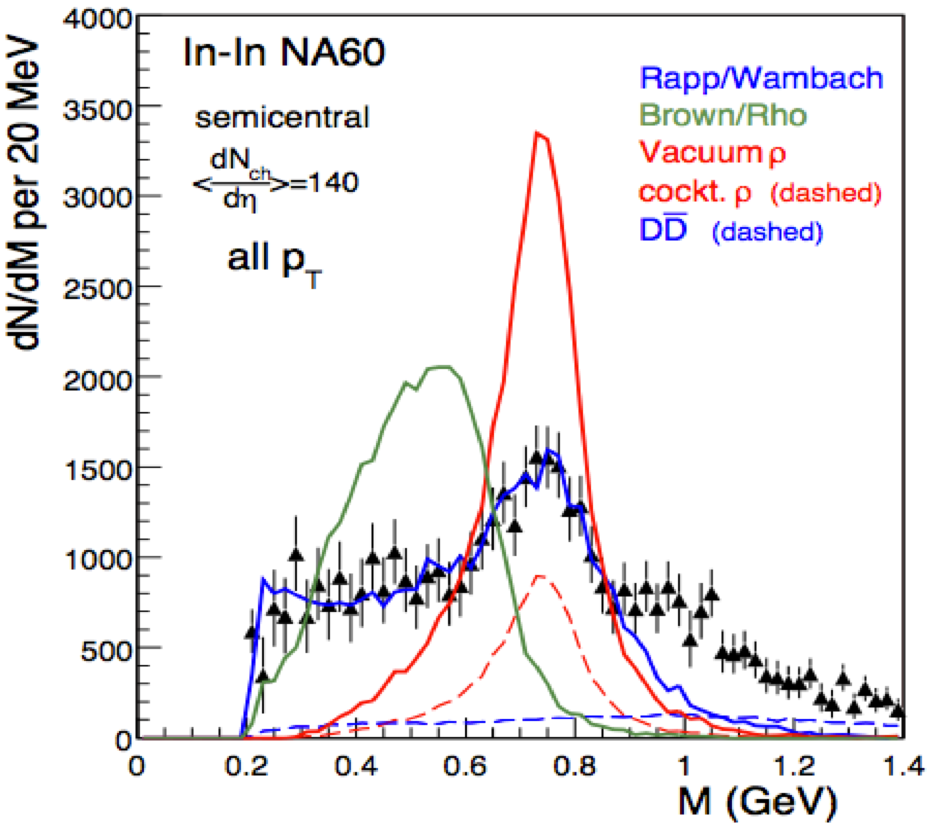
➢ **High mass region (HMR):**

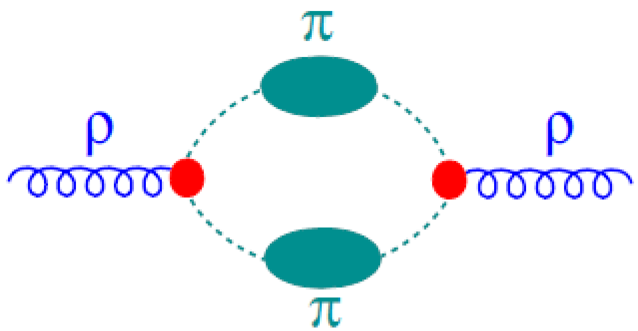
heavy quarkonia

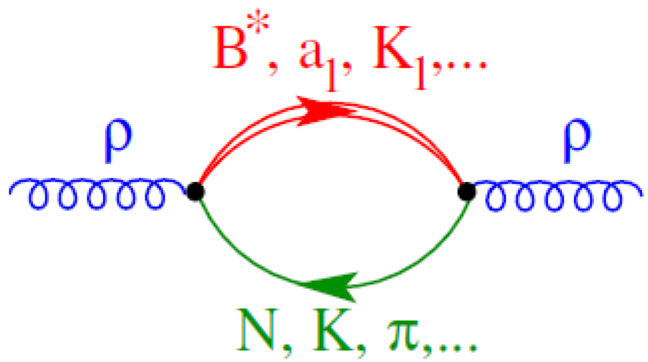
Drell-Yan contribution

Motivation - vector meson

NA60, PRL 96 (2006) 162302, PRL 100 (2008) 022302



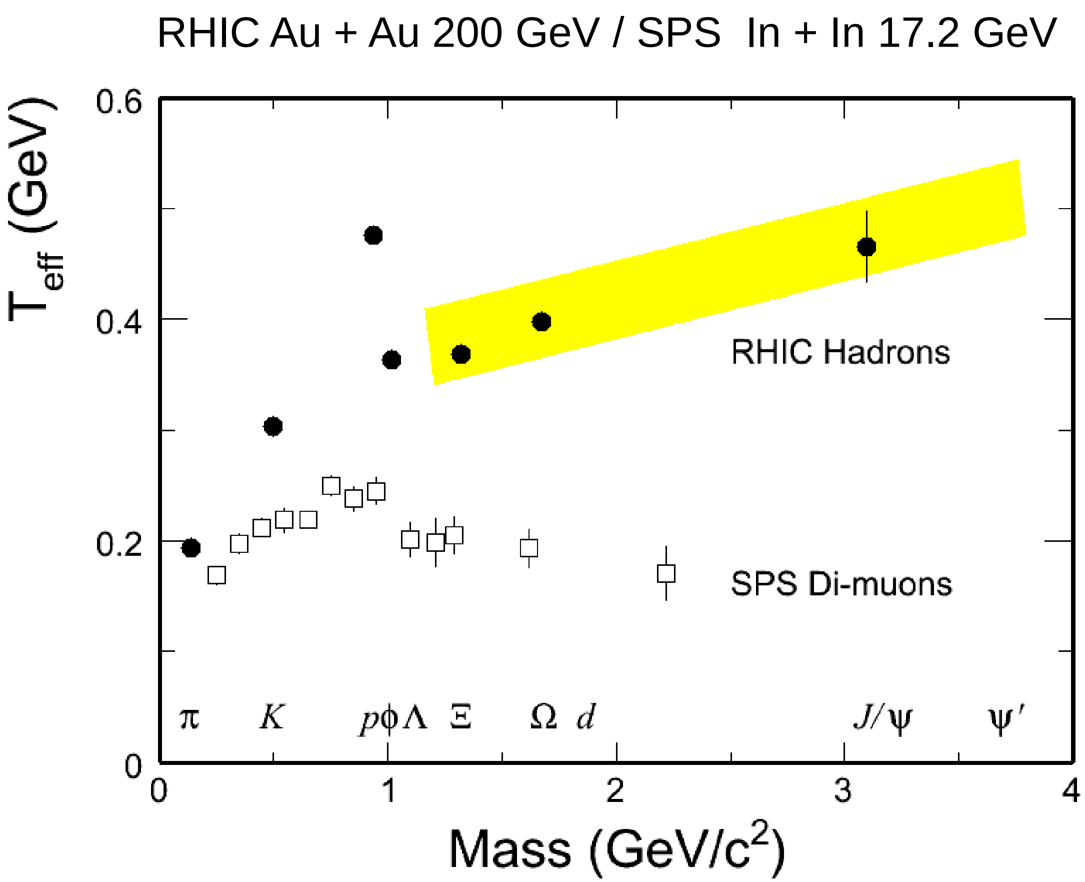




- **in-medium modifications of vector mesons**
- **chiral symmetry restoration**

ρ life time(~1.3 fm/c) less than hadronic medium(~10 fm/c) - excellent tool

Motivation - thermal radiation



NA60, PRL 100, 022302 (2008)

STAR, NPA 757,102 (2005)

PHENIX, PRL 98, 232301 (2007)

Different slope in m_T spectra in low and intermediate mass at SPS energy

➢ *"hint of partonic thermal dileptons"*

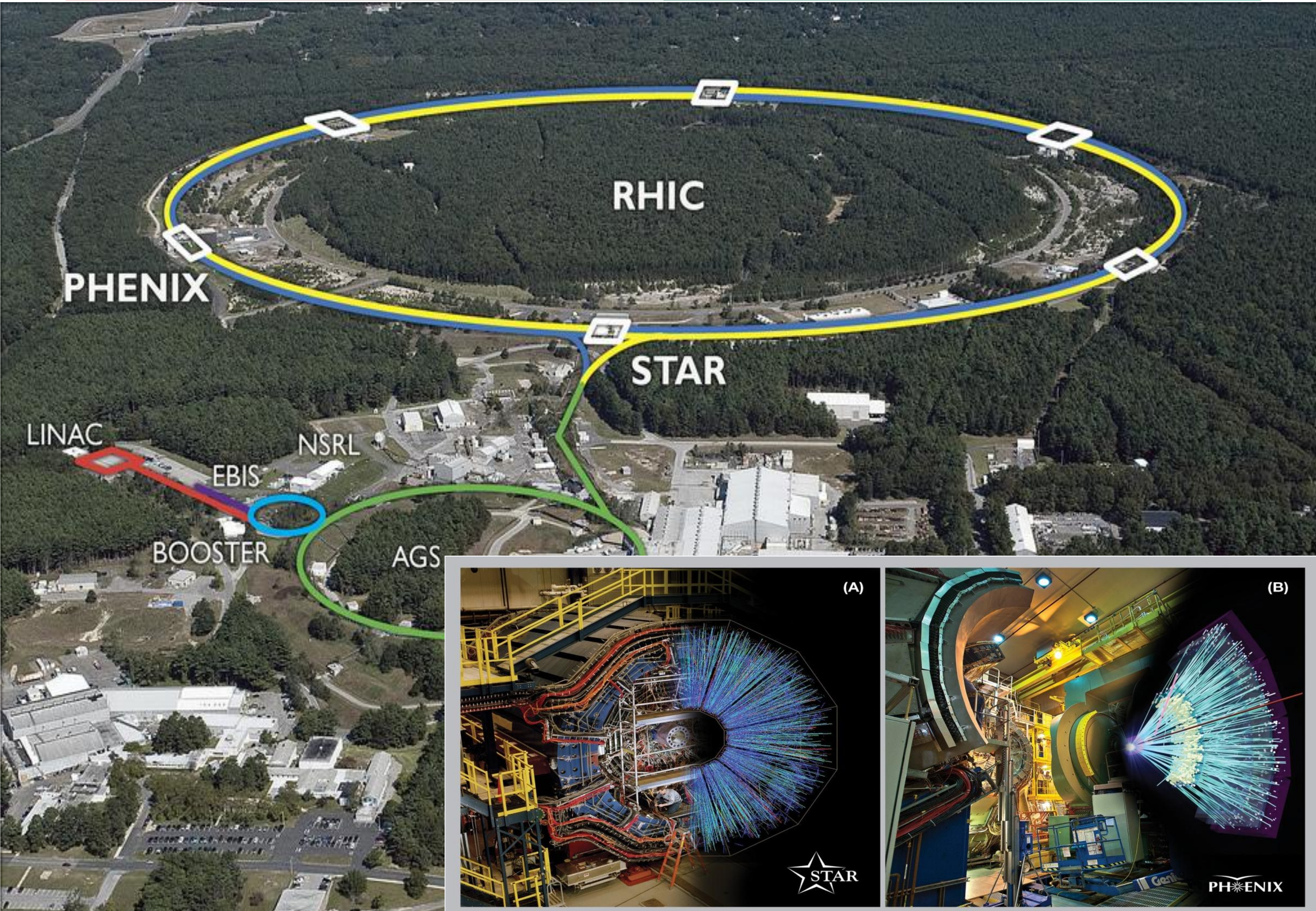
$$q\bar{q} \rightarrow l\bar{l}$$

What about at RHIC energy?

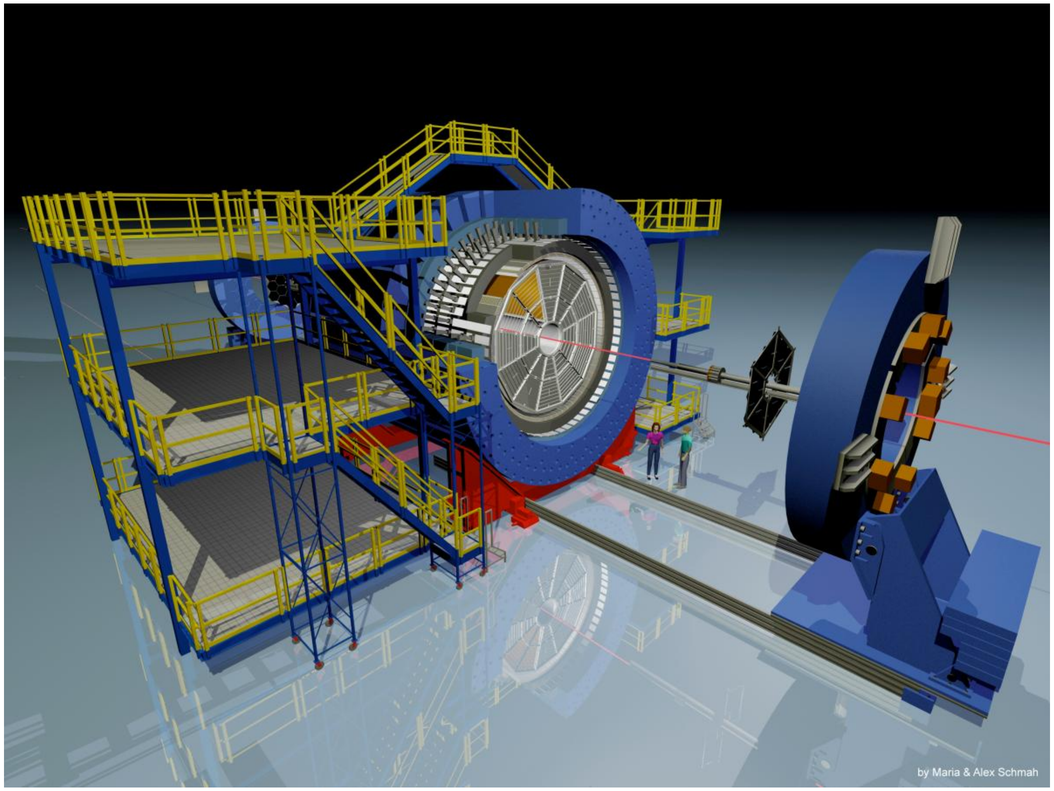
➢ **Experimental observables**

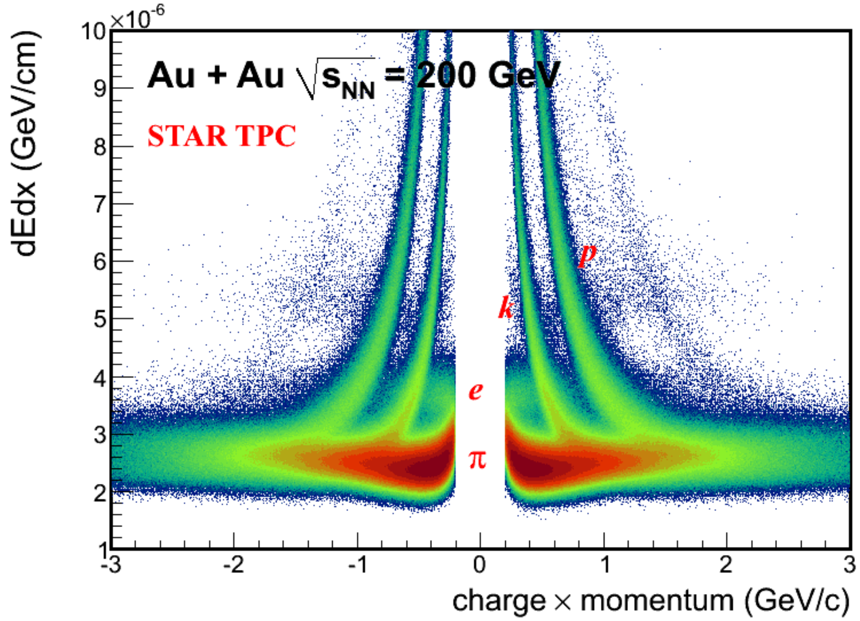
- *production cross section vs (mass, p_T)*
- *elliptic flow, polarization et al*

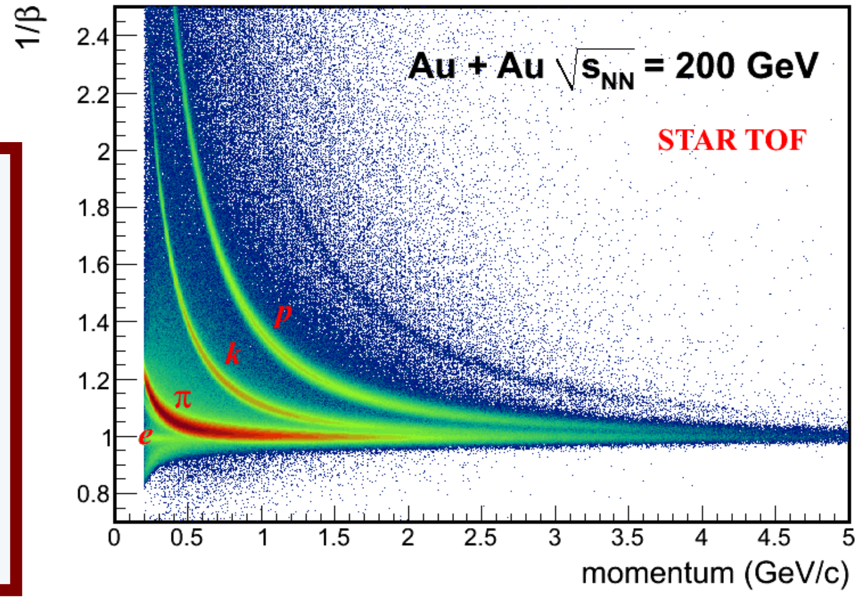
RHIC



STAR detector



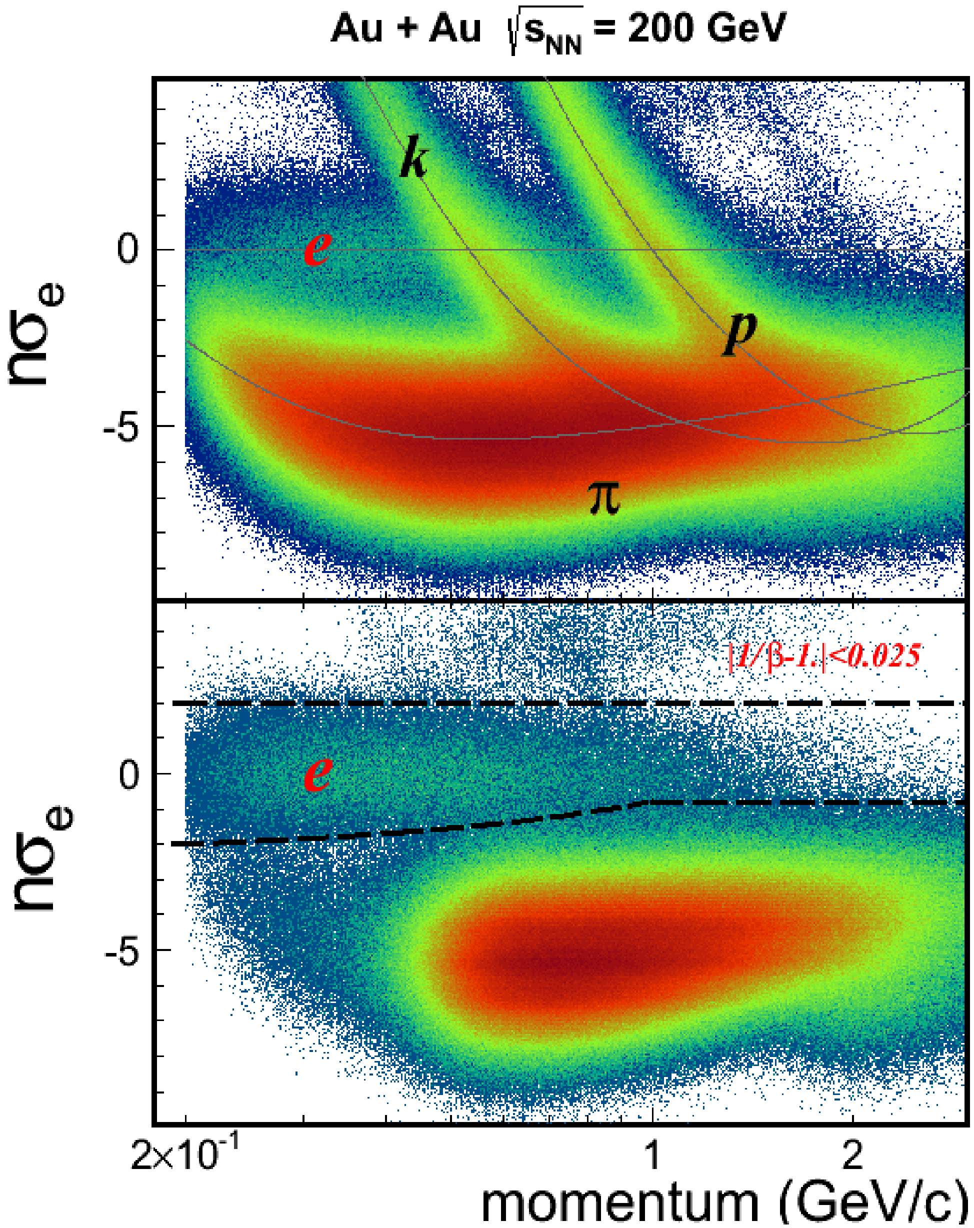


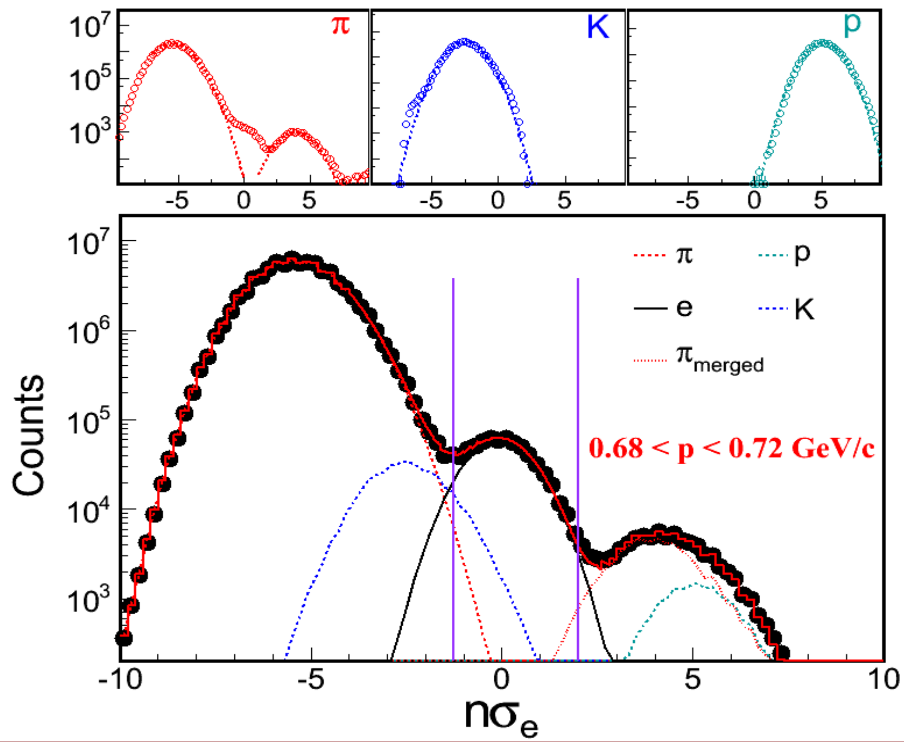


- **Time Projection Chamber** ($0<\phi<2\pi$, $|\eta|<1$)
  Tracking – momentum
  Ionization energy loss – dE/dx (particle identification)
- **Time Of Flight detector** ($0<\phi<2\pi$, $|\eta|<0.9$)
  Timing resolution <100ps - significant improvement for PID

Electron Identification

TOF velocity cut to remove slow hadrons



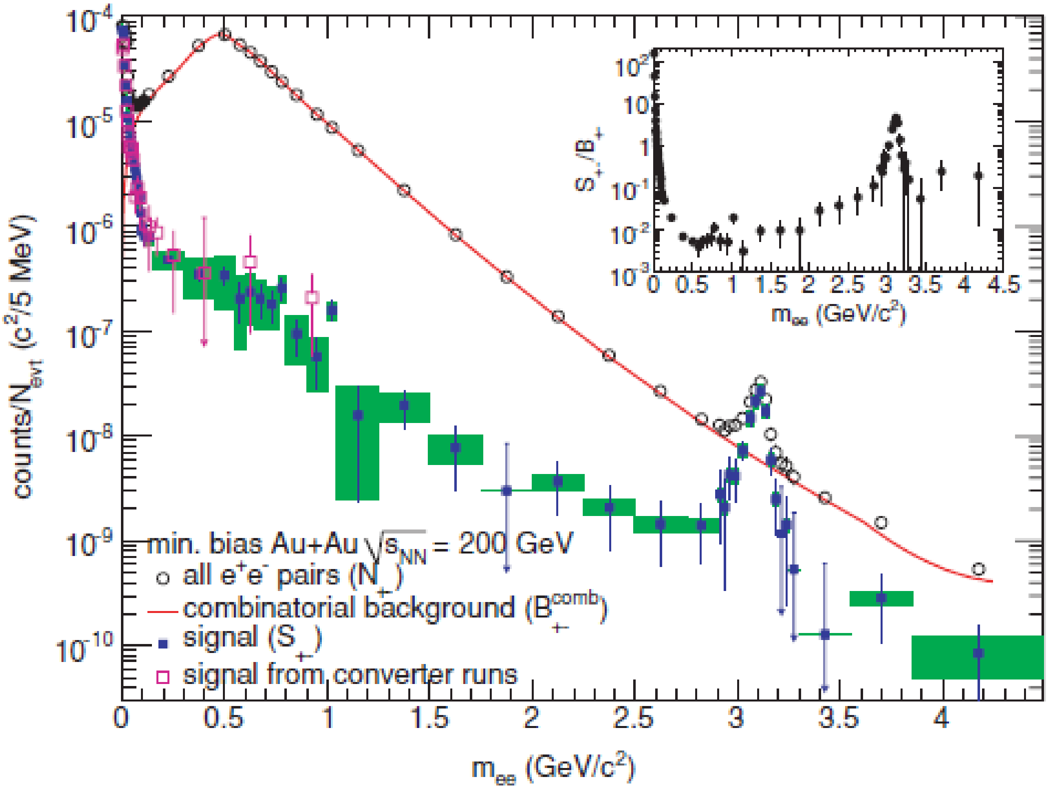


➢**Clean electron PID with a combination of TPC dE/dx and TOF velocity**

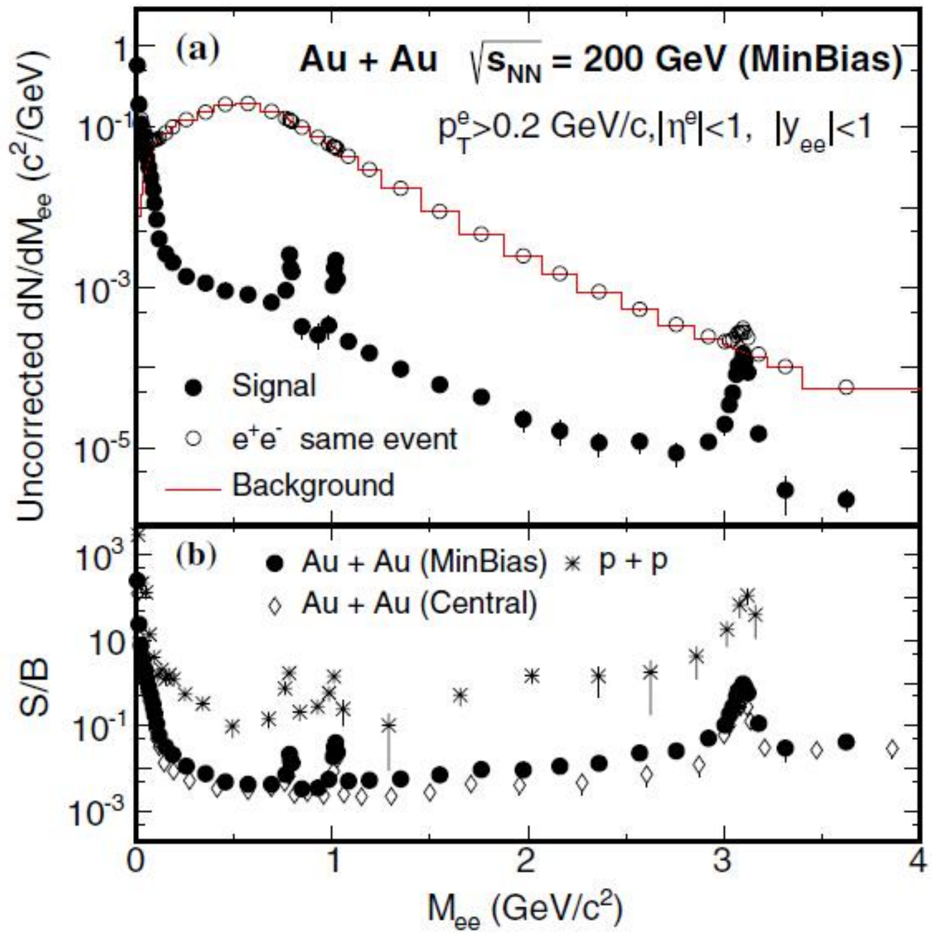
electron purity ~99% in pp , ~97% in AuAu MinBias.

hadron contamination contribution to the correlated background is small, and has been included in the systematic uncertainties (Au +Au).

Challenges



PHENIX, PRC 81 (2010) 034911;



STAR, PRL 113 (2014)022301;

➢Low S/B, ~ 1/200 in MinBias Au + Au collisions

Background Reconstruction

Like Sign:

$$1: B_{LikeSign} = 2\sqrt{N_{++} \cdot N_{--}} \cdot \boxed{\frac{B_{+-}^{Mix}}{2 \cdot \sqrt{B_{++}^{Mix} \cdot B_{--}^{Mix}}}}$$

Acceptance correction factor

$$2: B_{LikeSign} = a(N_{++} + N_{--}) \cdot \boxed{\frac{B_{+-}^{Mix}}{(B_{++}^{Mix} + B_{--}^{Mix})b}}$$

$$a = \frac{\int_0^\infty 2 \cdot \sqrt{N_{++} \cdot N_{--}}\, dmdpT}{\int_0^\infty (N_{++} + N_{--})\, dmdpT} \quad , \quad b = \frac{\int_0^\infty 2 \cdot \sqrt{B_{++}^{mix} \cdot B_{--}^{mix}}\, dmdpT}{\int_0^\infty (B_{++}^{mix} + B_{--}^{mix})\, dmdpT}$$

MixEvent:

- normalize mixed likeSign ++ and -- to same event ++ and --

$$A_{+} = \frac{\int_{N.R.} N_{++} dmdpT}{\int_{N.R.} B_{++}^{Mix} dmdpT}, \qquad A_{-} = \frac{\int_{N.R.} N_{--} dmdpT}{\int_{N.R.} B_{--}^{Mix} dmdpT}$$

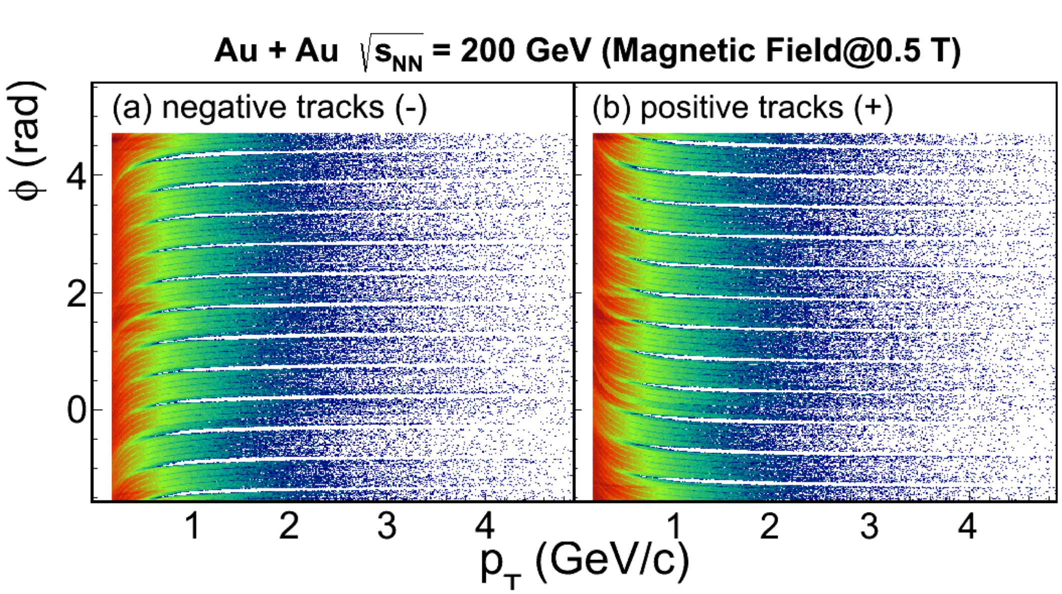
$$B_{++}^{mix} = \int_0^\infty A_{+} B_{++}^{mix} dmdpT, \qquad B_{--}^{mix} = \int_0^\infty A_{-} B_{--}^{mix} dmdpT$$

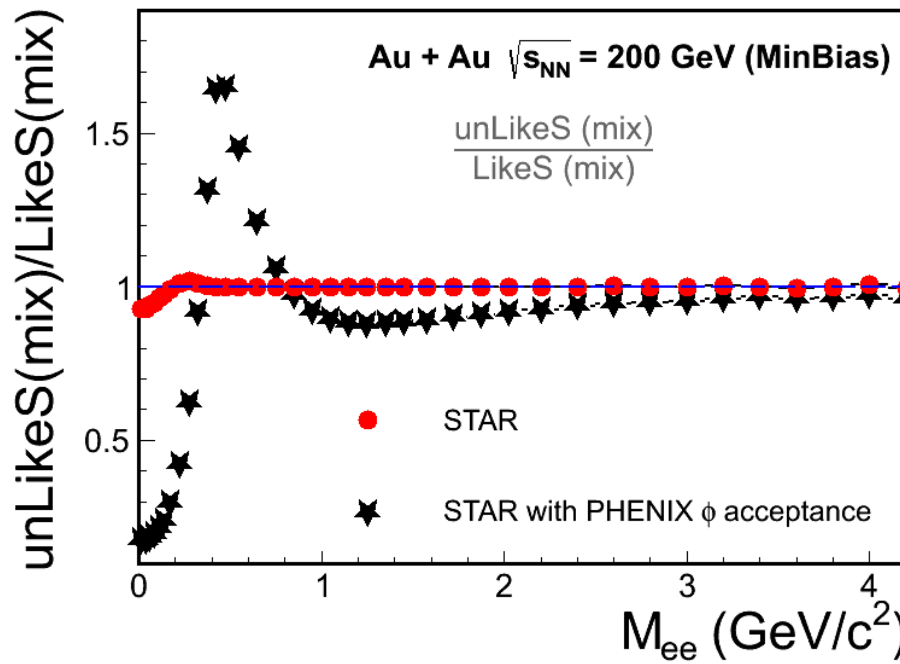
- normalize mixed unlikeSign (combinatorial background)

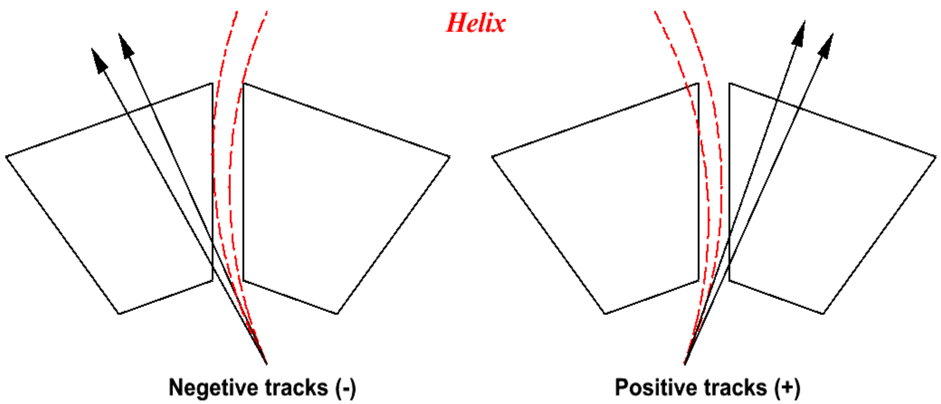
$$B_{+-}^{combinatorial} = a \cdot \frac{2\sqrt{B_{++}^{mix} \cdot B_{--}^{mix}}}{\int_0^\infty B_{+-}^{mix} dmdpT} B_{+-}^{mix} \qquad (a = sum_{+-}/2\sqrt{sum_{++} \cdot sum_{--}}, \text{ w/o normalization})$$

Compare to like-sign: enough statistics, no **acceptance** correction,
but can't reproduce **correlation** background, e.g. cross pair etal.

Like-Sign Background







➢**Different acceptance between Like-Sign pairs and unLike-Sign pairs**

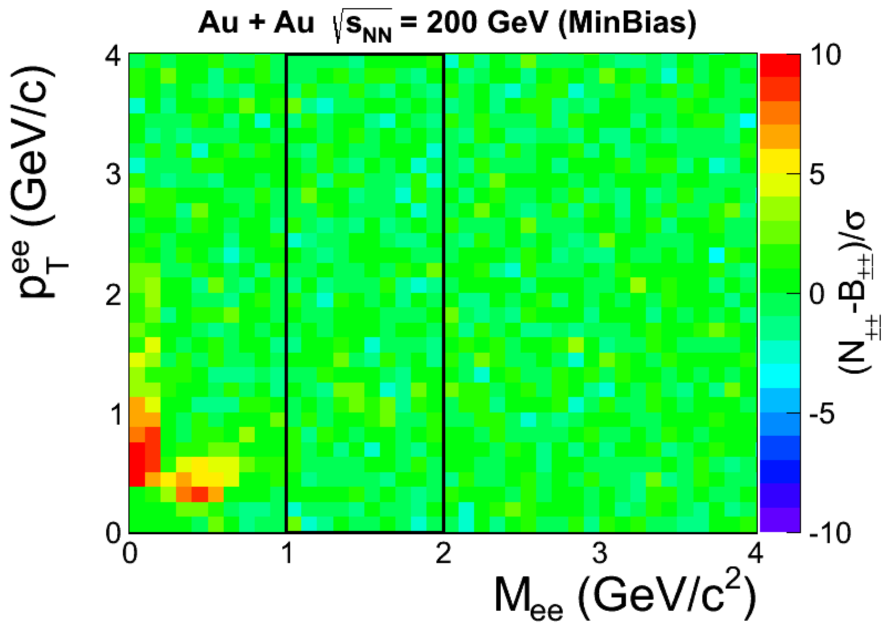
strong pT dependence

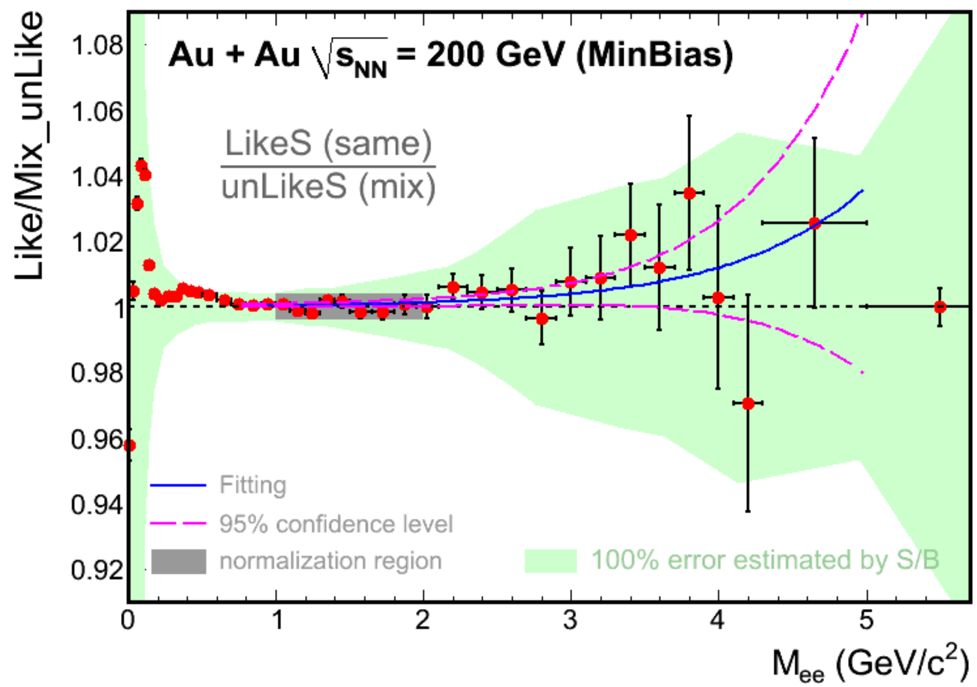
slightly centrality dependence

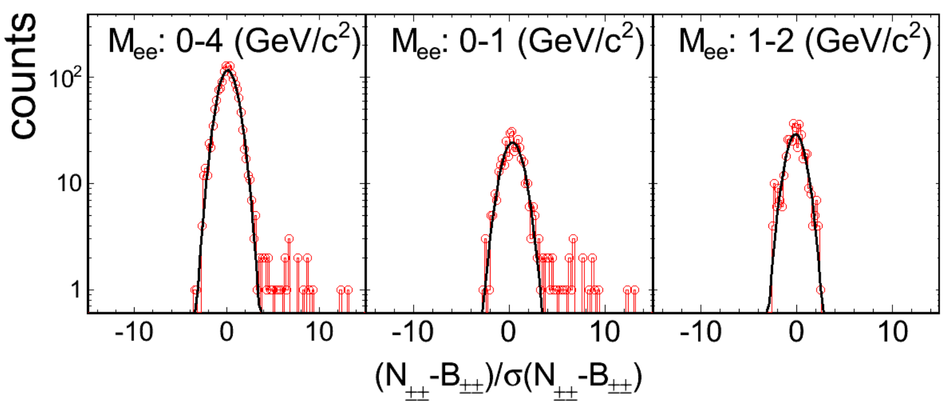
more obviously in PHENIX acceptance

uncertainity: ~0.05%

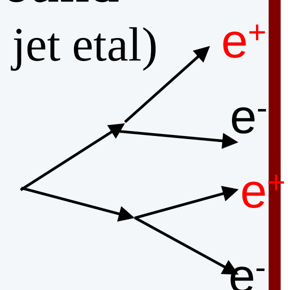
Mix-Event Background







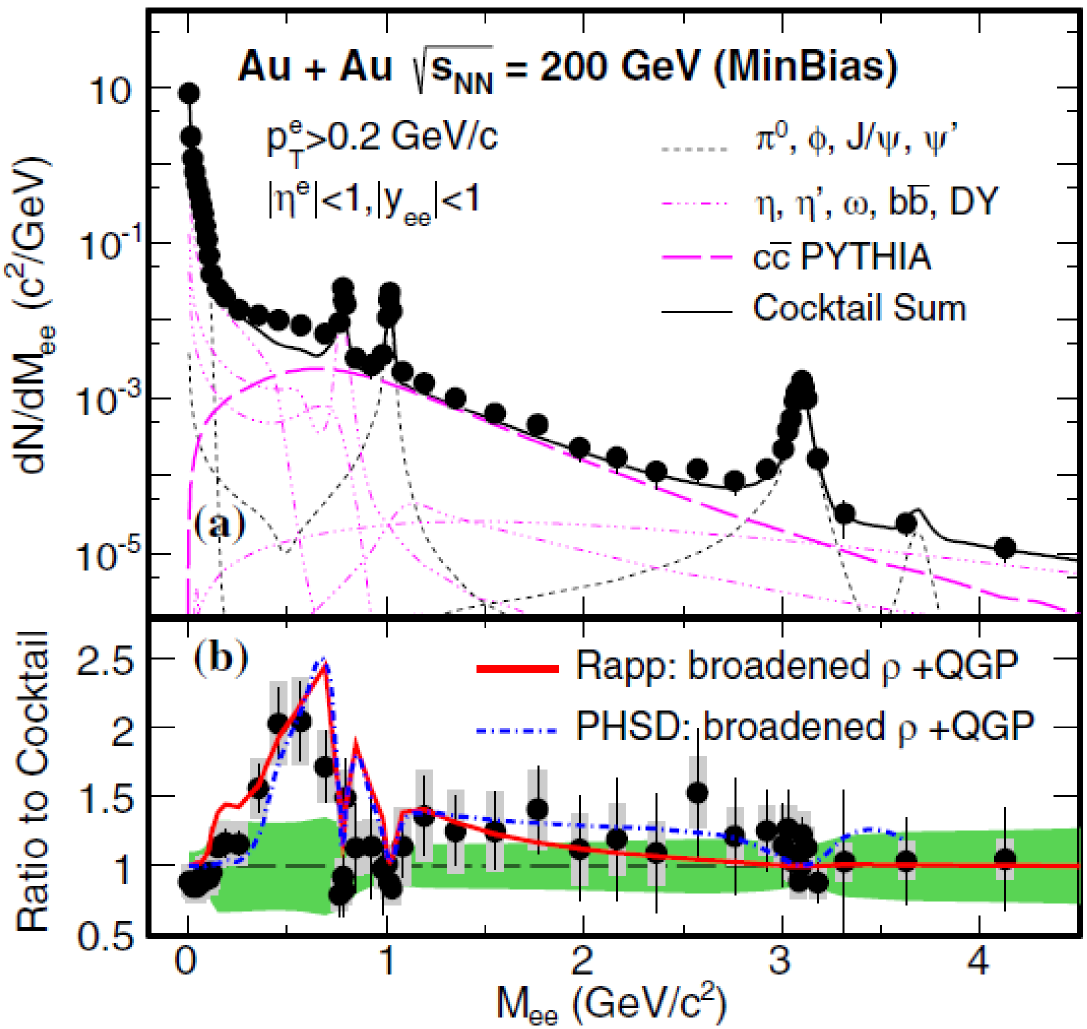
- **Mix-event normalization in two demesion**
- **Like-Sign and Mix-Event background**
  - correlation background (cross pair, jet etal)
  - different statistics
  - acceptance uncertainity



LMR (<1GeV/c^2): Like-Sign
IM+HMR(>1GeV/c^2): Mix-Event(Like-Sign)

Results from RHIC Top Energy

STAR, PRL 113 (2014)022301;



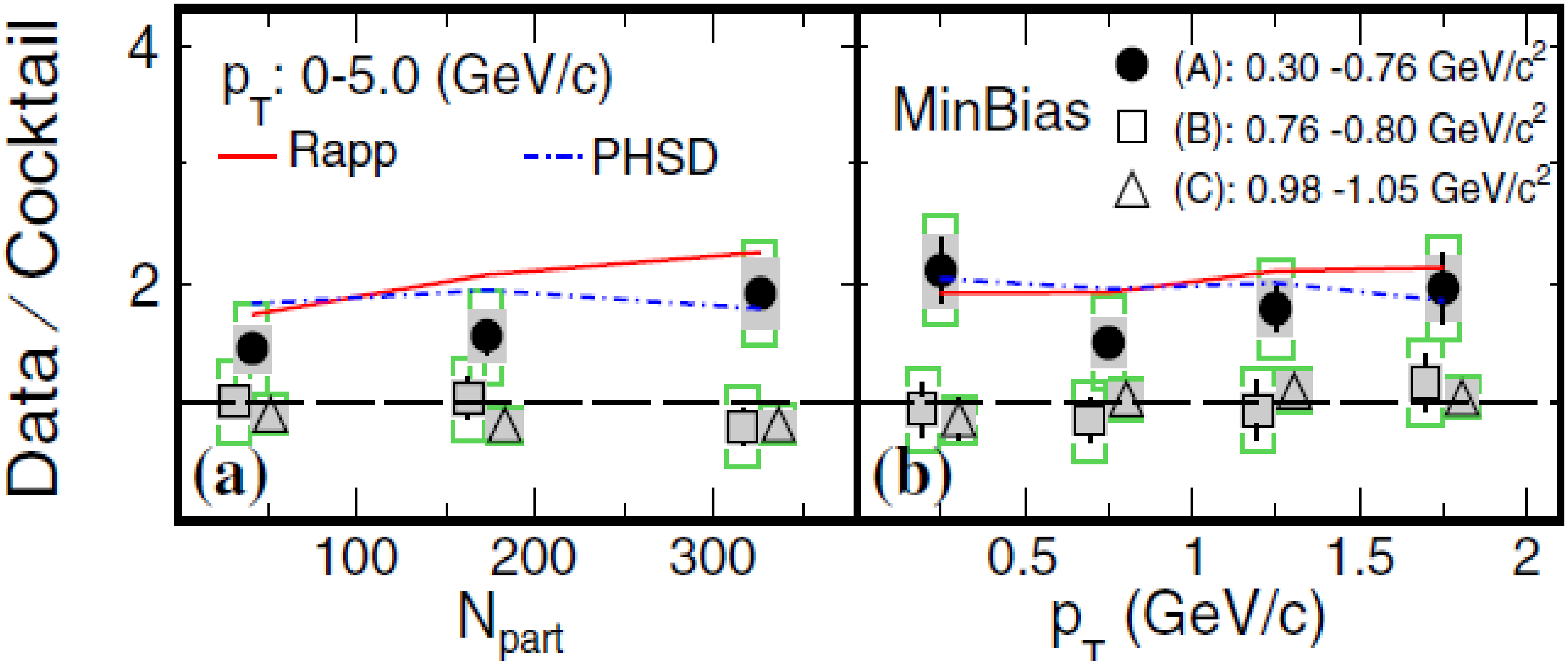
Models show good agreement with data within uncertainty.

- Enhancement at ρ like region(0.30-0.76 GeV/c2): 1.77±0.11(stat,)±0.24(sys,)±0.41 (cocktail) in MinBias Collisions.

- Compared with models based on ρ broadening :
  1) Model I: by Rapp et al. effective many-body model. [R. Rapp, PoS CPOD2013, 008 (2013)]
  2) Model II: microscopic transport model: Parton-Hadron-String -Dynamics (PHSD). [O. Linnyk et al., Phys. Rev. C 85, 024910 (2012)]

Results from RHIC Top Energy

STAR, PRL 113 (2014)022301;



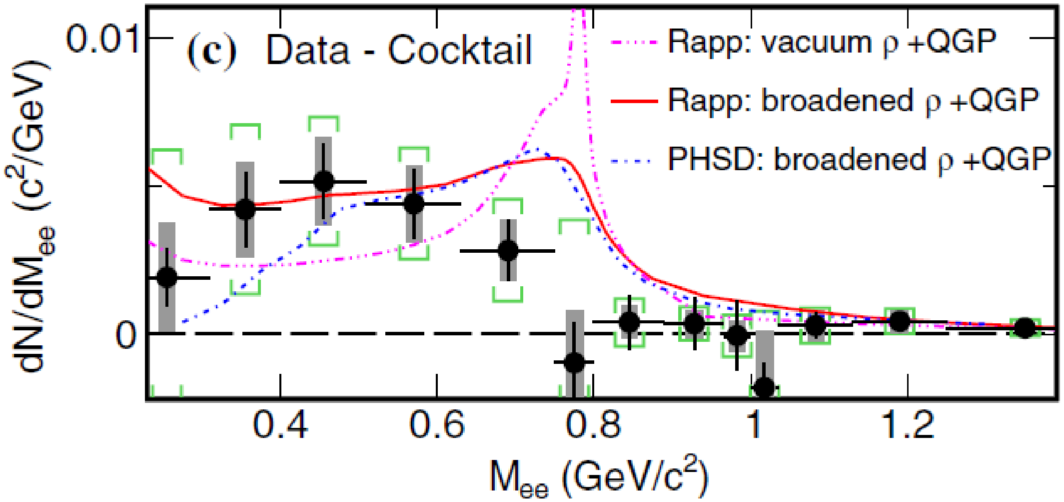
ρ like region
ω region
ϕ region

- **ρ like region (A):**
  The enhancement shows weak dependence on centrality and pT.
- **ω and ϕ region (B), (C):**
  Cocktail can reproduce the yield

Results from RHIC Top Energy

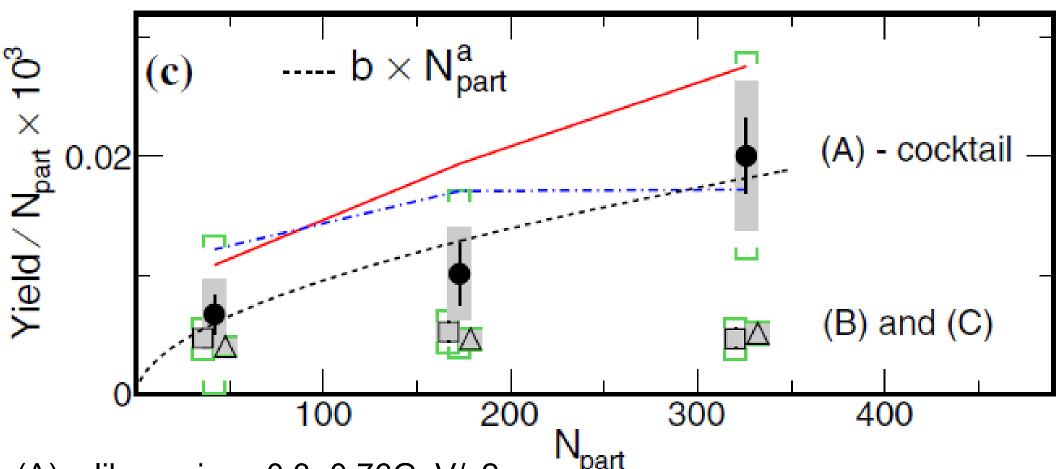
1) excess in LMR (MinBias) :

STAR, PRL 113 (2014)022301;



- Broadened ρ model explain can STAR data within uncertainties.
- STAR measurements disfavor a pure vacuum ρ model in 0.3~1 GeV/c2

2) Npart dependence of excess yield:



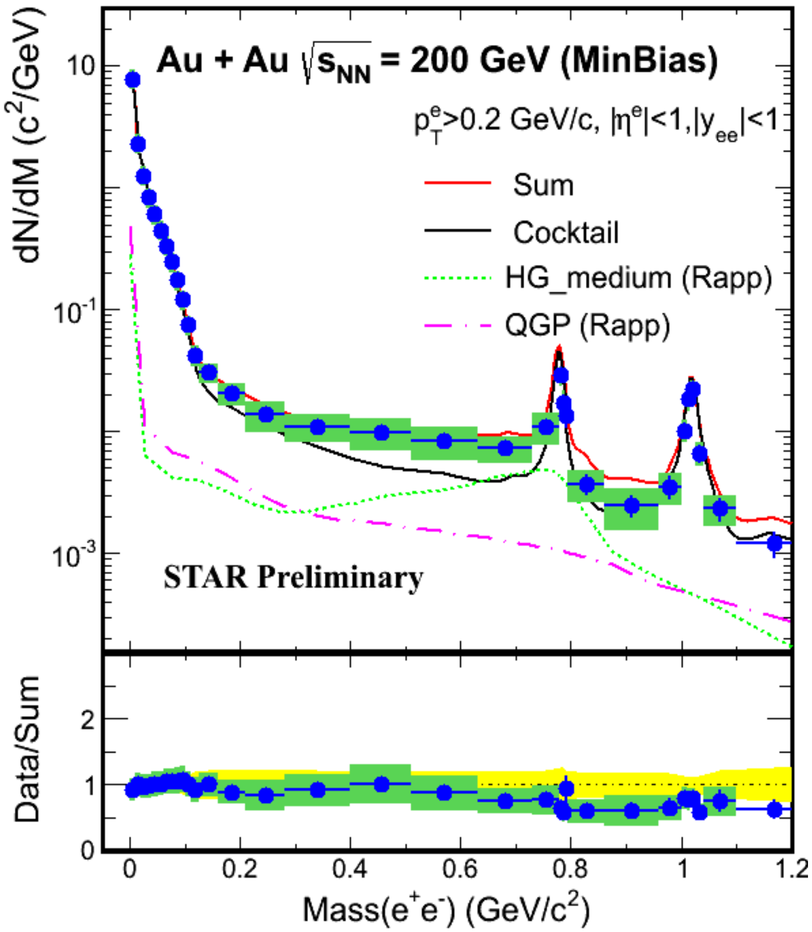
(A) ρ like region : 0.3~0.76GeV/c2
(B) ω region: 0.76~0.80GeV/c2
(C) ϕ region: 0.98~1.05GeV/c2

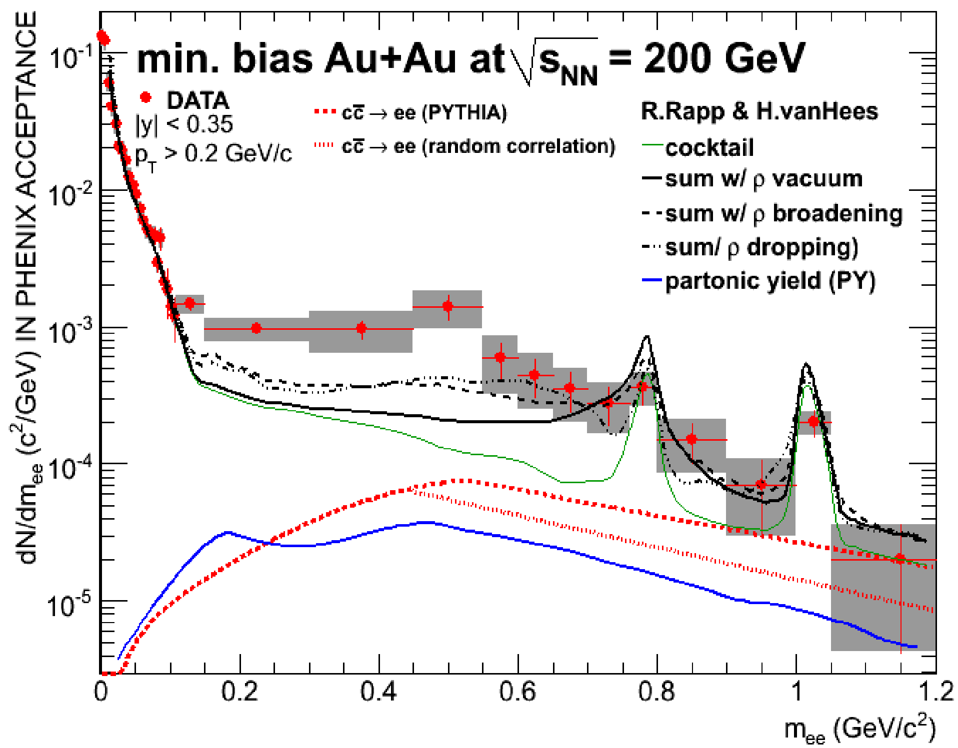
- ω and ϕ region (B), (C): Yield shows Npart scaling.
- ρ like region (A): Significant excess. Sensitive to the QCD media dynamics. A power fit shows:

"ρ–clock"

$$Yield \propto N_{part}^{1.54\pm0.18}$$

Comparison on Low Mass Enhancement



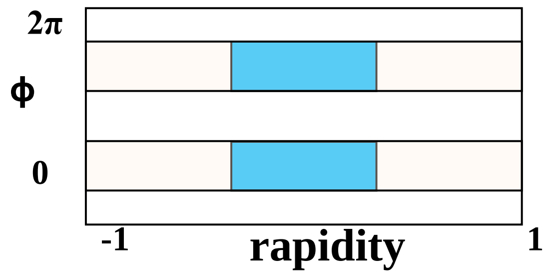


PHENIX PRC 81 (2010) 034911; STAR QM11

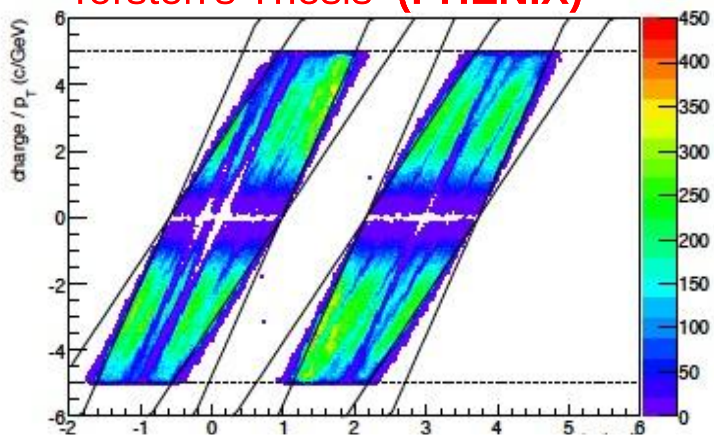
Enhancement factor in $0.15<M_{ee}<0.75$ Gev/c^2

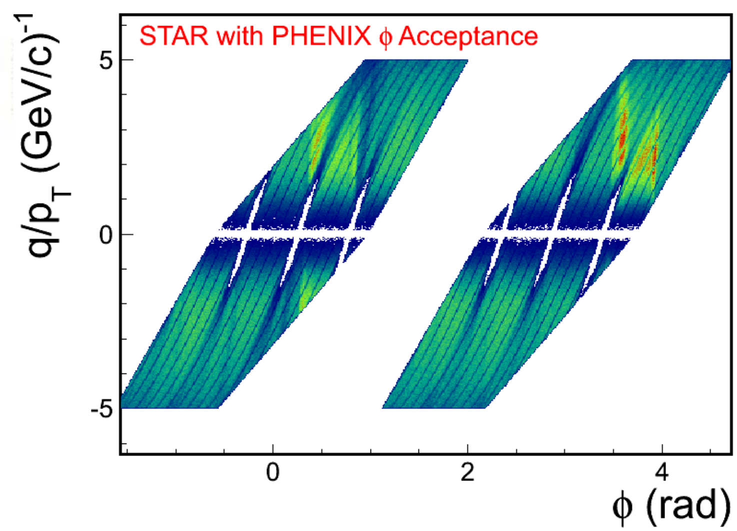
	Minbias (value ± stat ± sys)	Central (value ± stat ± sys)
STAR	1.53 ± 0.07 ± 0.41 (w/o ρ) 1.40 ± 0.06 ± 0.38 (w/ ρ)	1.72 ± 0.10 ± 0.50 (w/o ρ) 1.54 ± 0.09 ± 0.45 (w/ ρ)
PHENIX	4.7 ± 0.4 ± 1.5	7.6 ± 0.5 ± 1.3
Difference	2.0 σ	4.2 σ

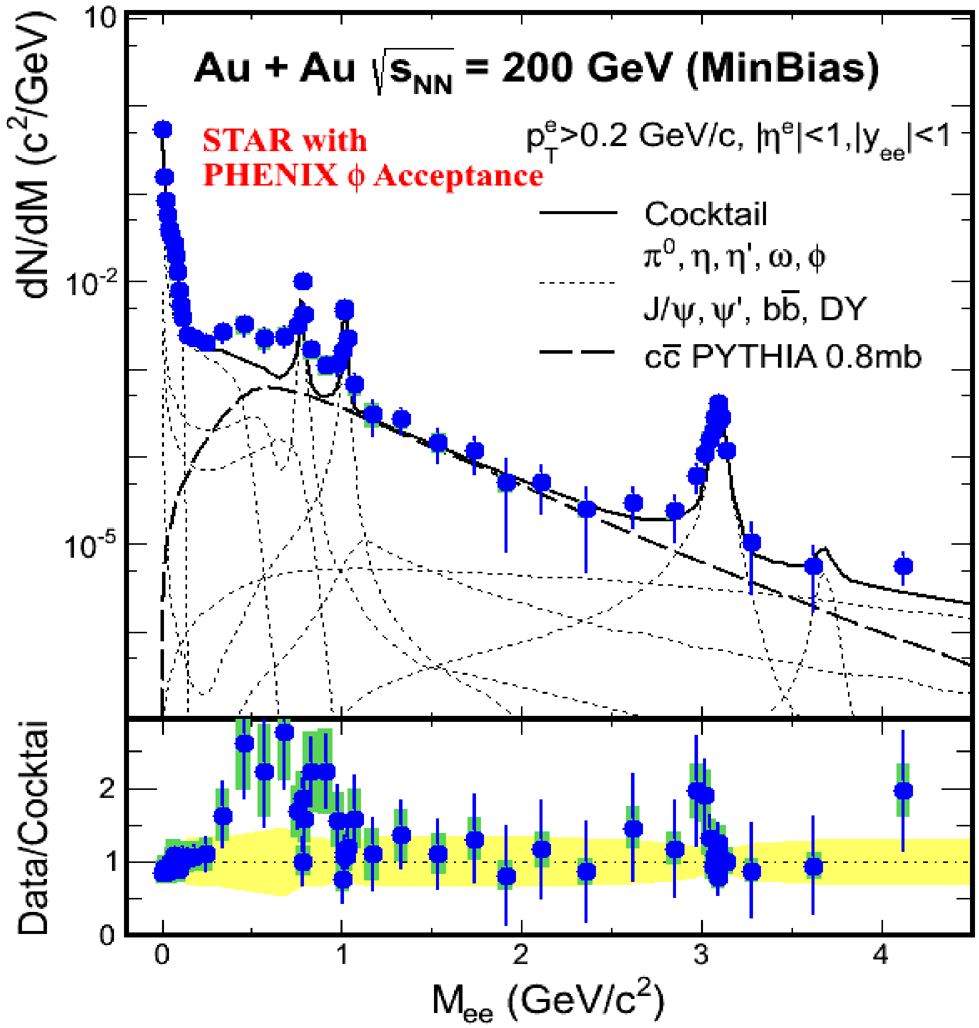
Acceptance Effect



Torsten's Thesis **(PHENIX)**



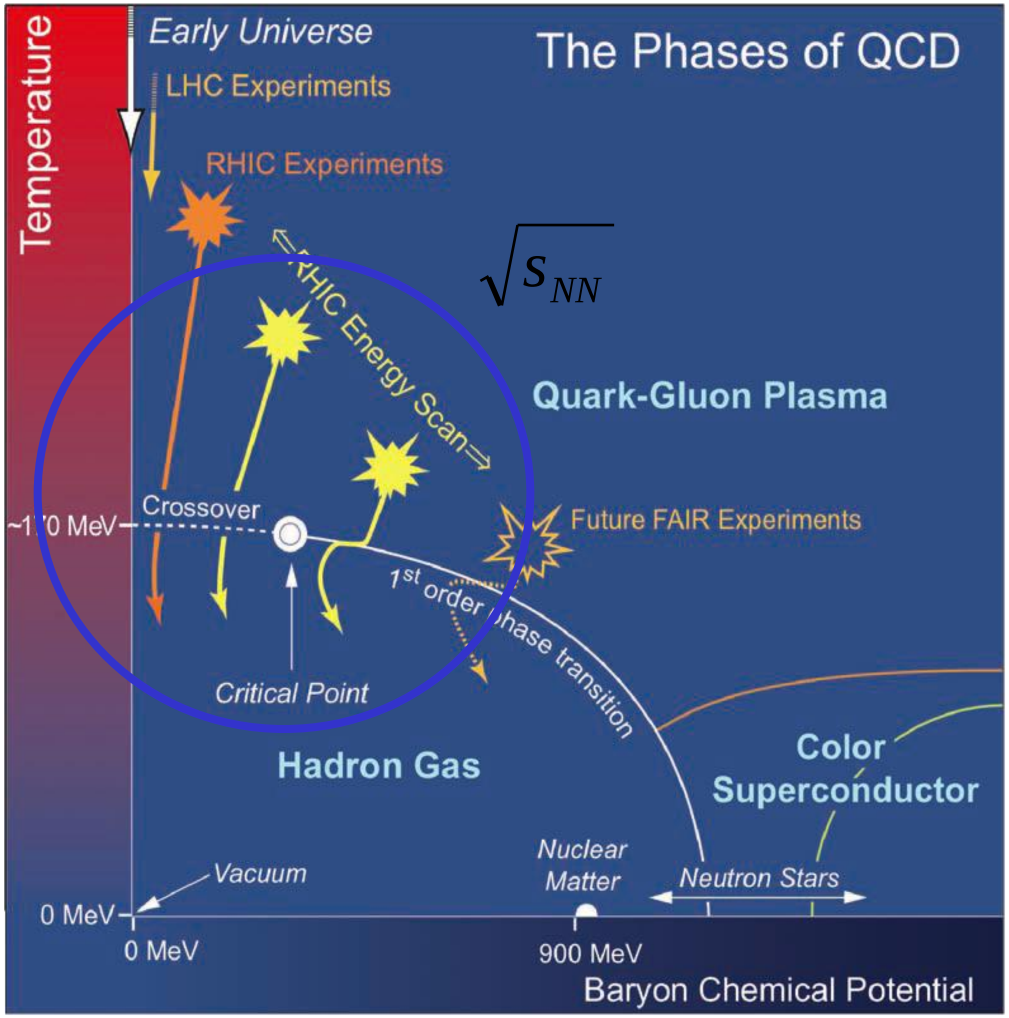




- **Au+Au 200 GeV MinBias Collisions**
  STAR data after PHENIX Φ acceptance:
  LMR enhancement factor still ~ 2

Beam Energy Scan at RHIC

NSAC Long Range Plan 2007



0) Turn-off of sQGP signatures

1) Search for the phase boundary

2) Search for the critical point

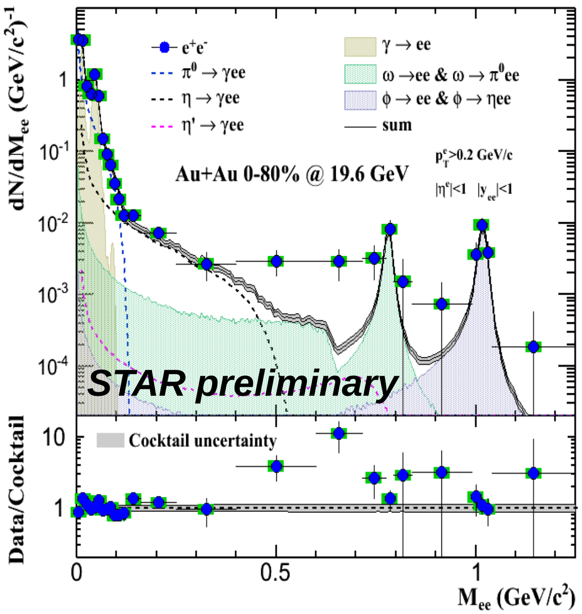
BES Phase-I

Year	$\sqrt{s_{NN}}$ (GeV)	Events(10^6)
2010	39	130
2011	27	70
2011	19.6	36
2014	14.5	22
2010	11.5	12
2010	7.7	5

Compared to SPS

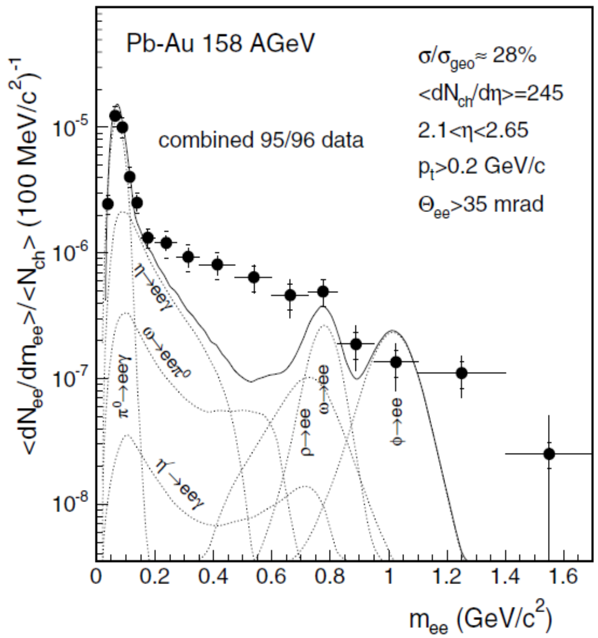
STAR QM12

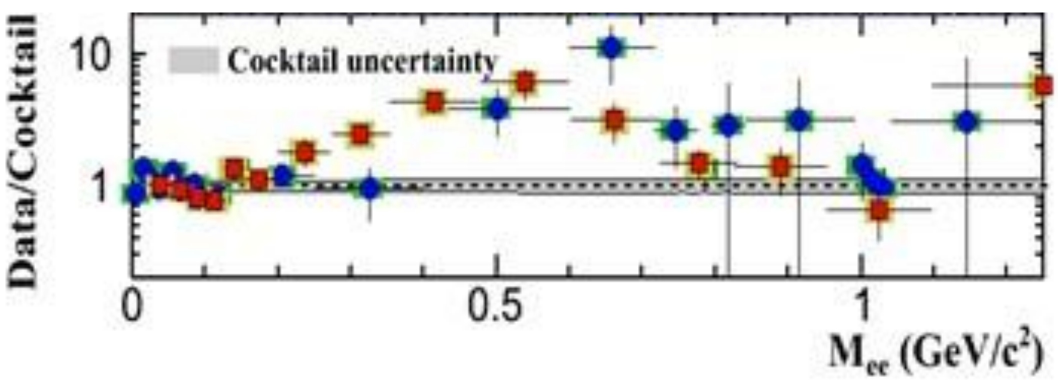
19.6 GeV



NA45/CERES

17.2 GeV



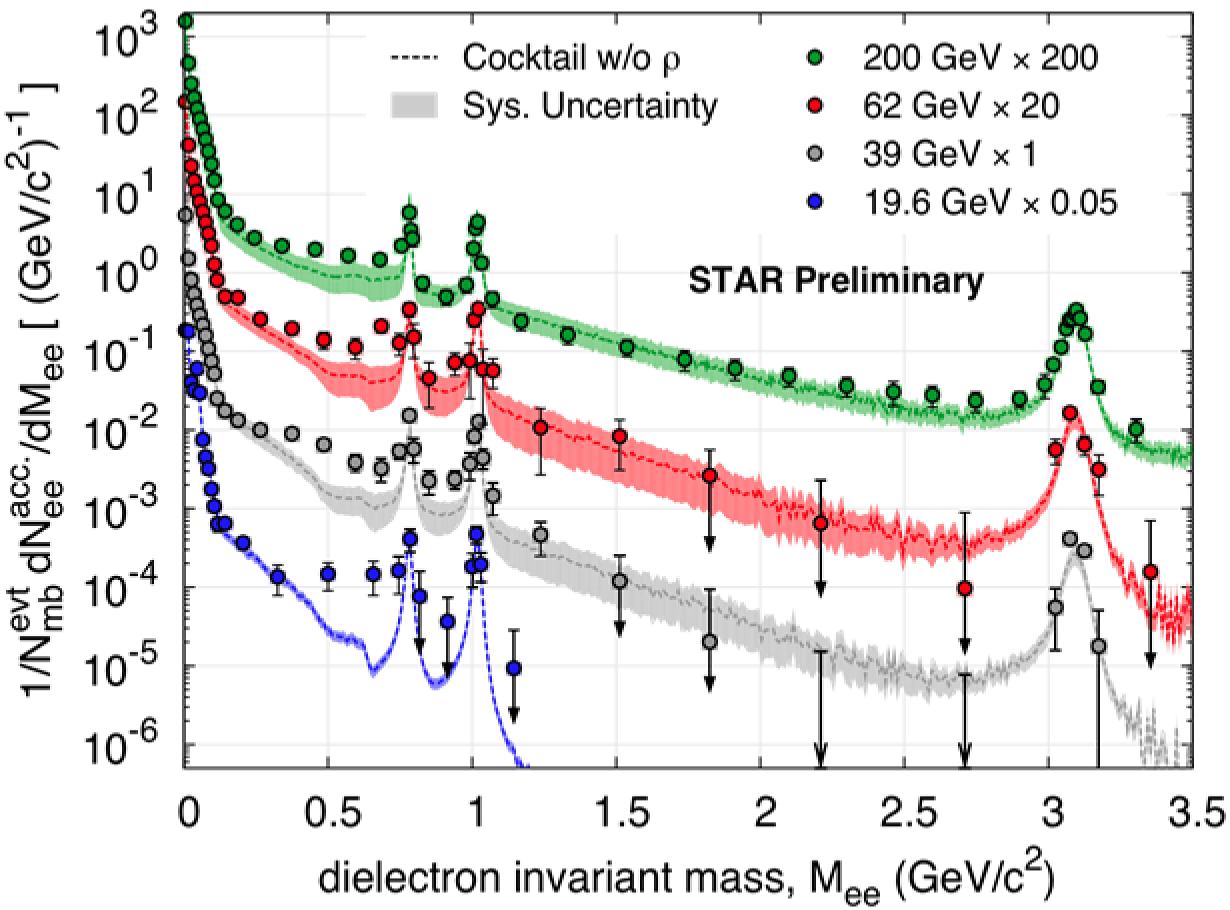


- **π yield is from STAR π^{+-} measurement, other meson yields derived from SPS meson/π^0 ratio.**
- **Different centrality & acceptance**
  - **- STAR Au+Au:**
    0-80% centrality
    $p_T>0.2$ GeV/c, $|\eta|<1$, $|y_{ee}|<1$.
  - **- CERES Pb+Au:**
    0-28% centrality.
    $p_T>0.2$GeV/c, $2.1<\eta<2.65$, $\theta_{ee}>35$mrad
- **Different detector resolution.**

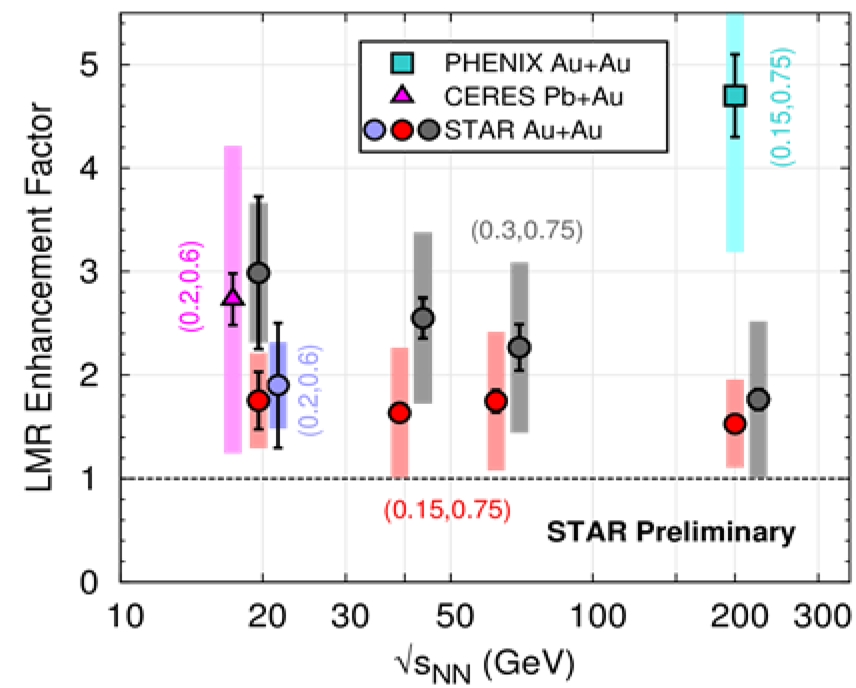
Enhancement factor	$0.2<M_{ee}<0.6$ GeV/c^2
STAR	$1.9 \pm 0.6 \pm 0.4$
CERES	$2.73 \pm 0.25 \pm 0.65 \pm 0.82$[decays]

Low mass enhancement comparable to CERES

Dielectrons from BES



STAR QM12



Enhancement in 0.3-0.75 GeV/c² shows a slight decreasing vs. collision energy

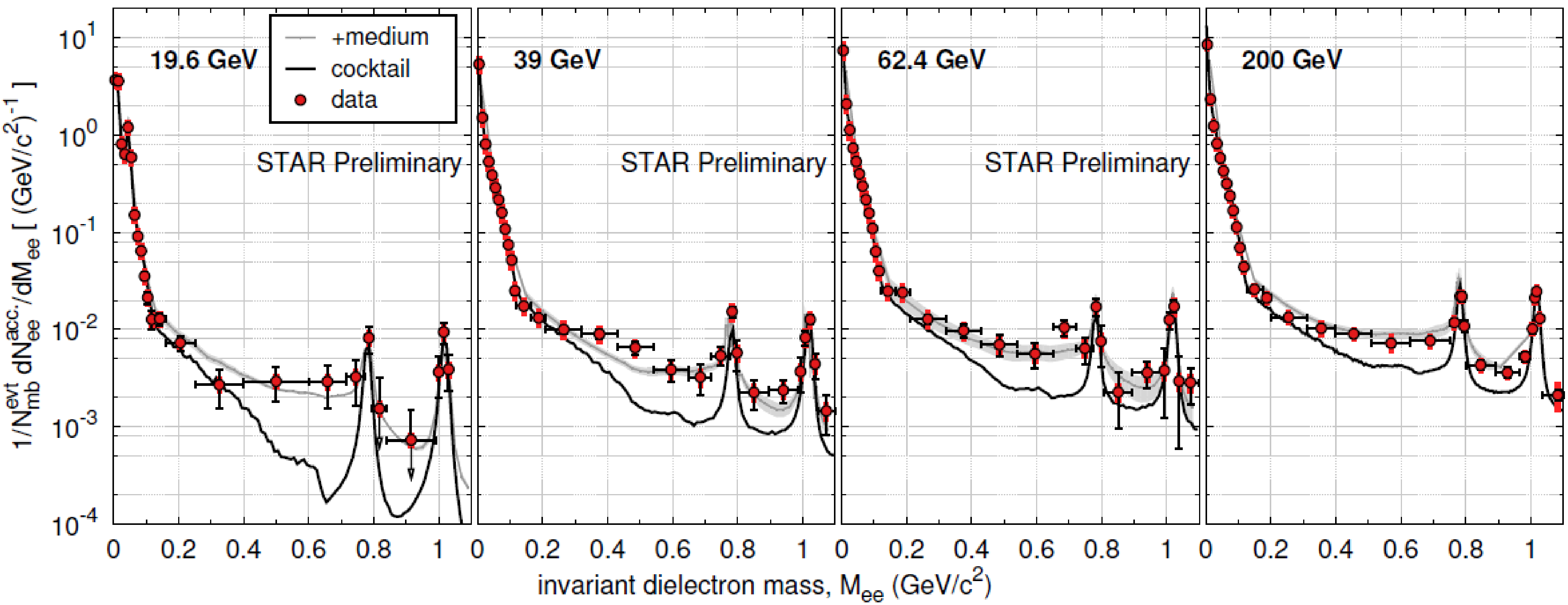
- charm contribution increasing significantly with energy

Dielectron Production 19.6-200 GeV

STAR BES white paper

In-medium ρ broadening

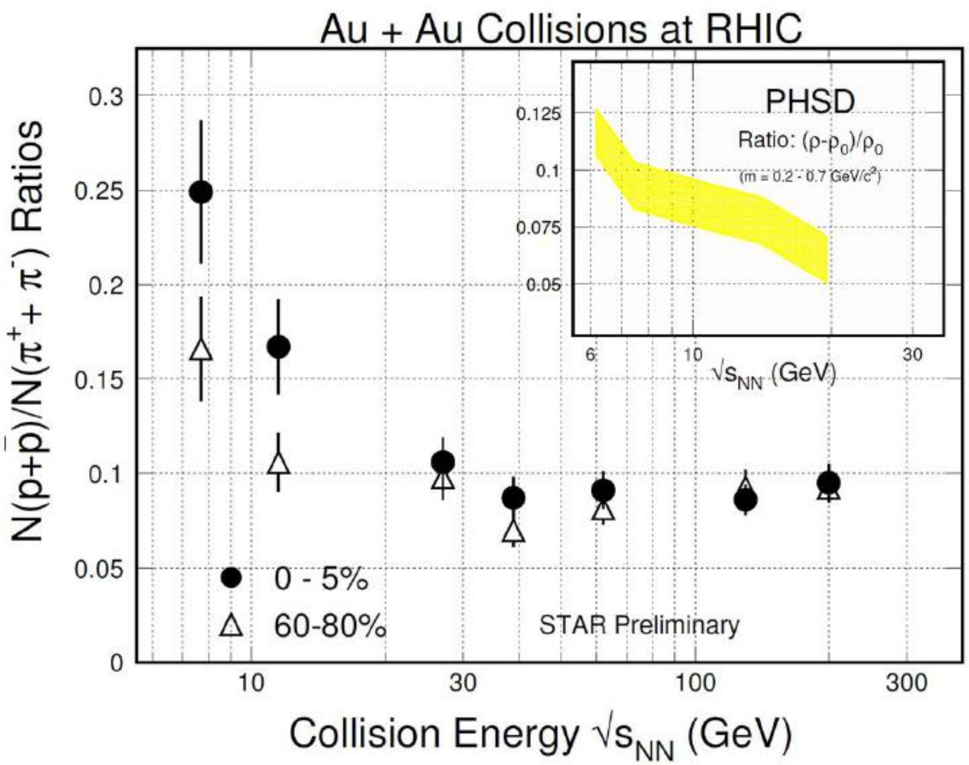
R. Rapp: private communications

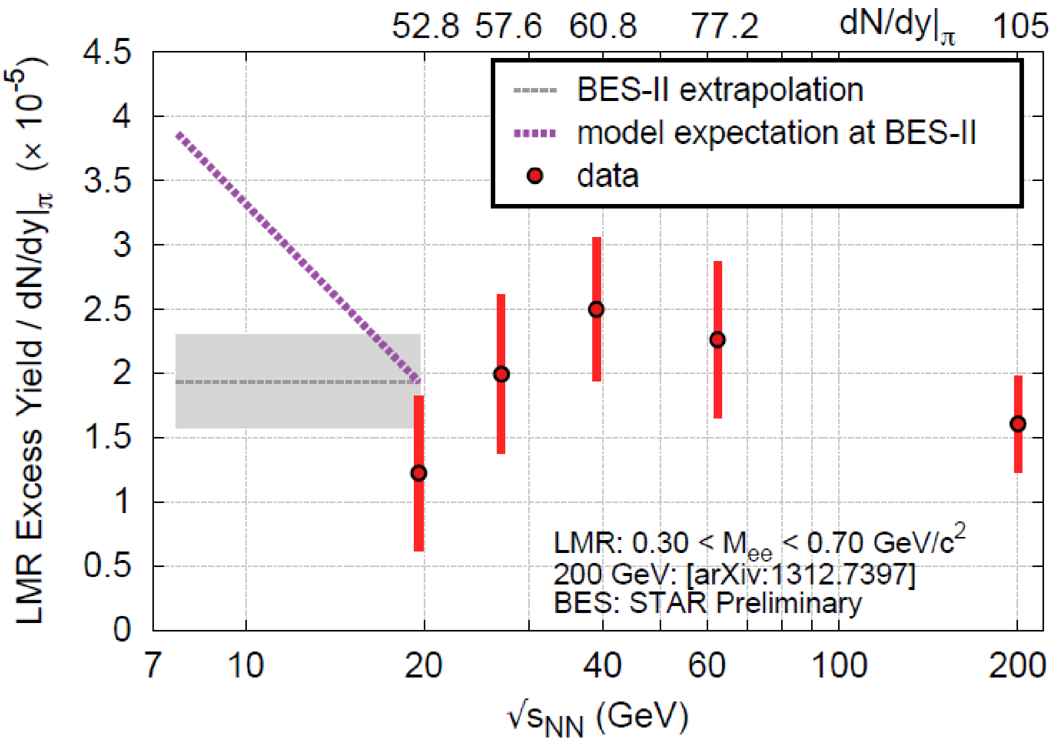


➢ **Model calculations by Rapp, based on in media broadening of ρ spectra function, expected to depend on total baryon density.**

Dielectron Production 19.6-200 GeV

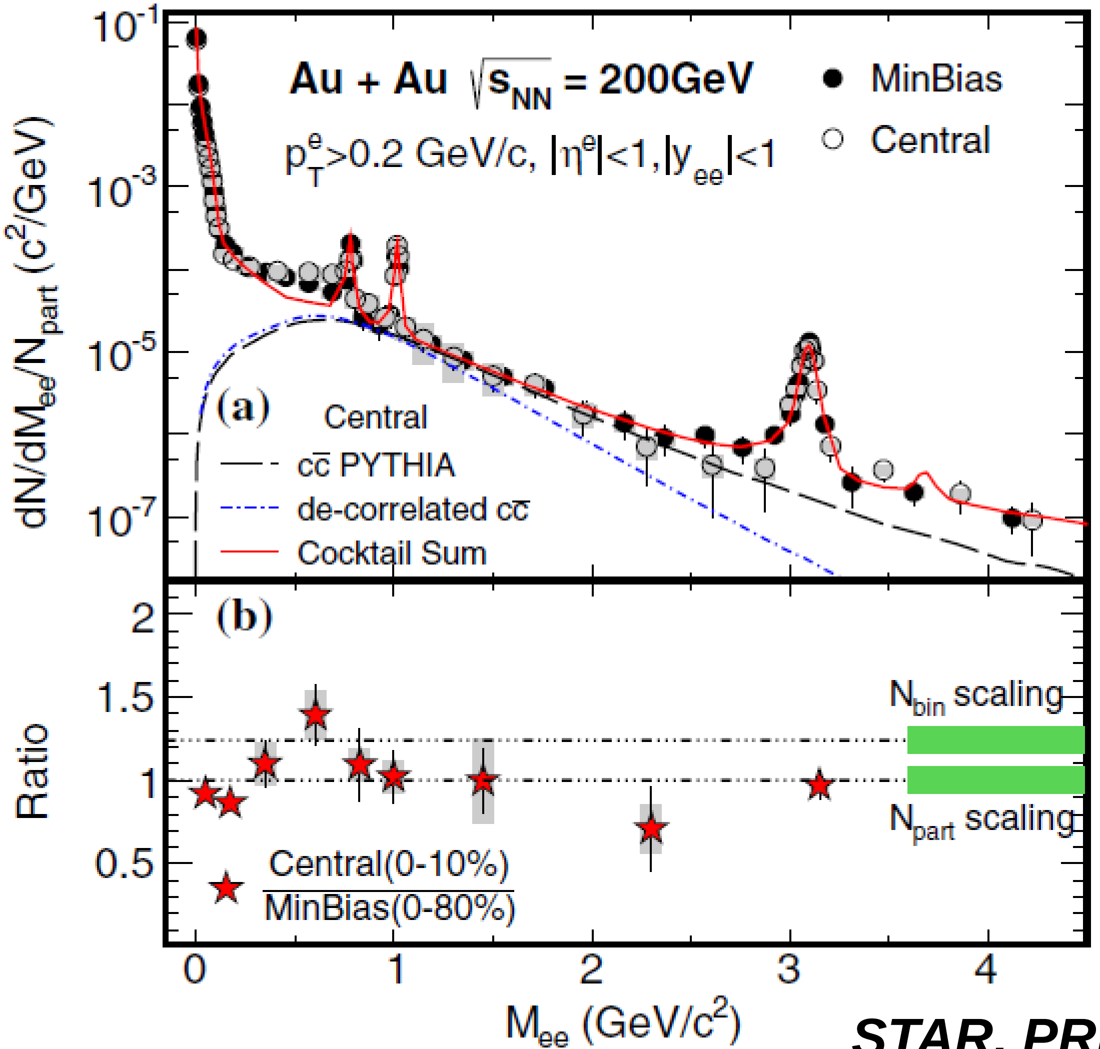
STAR BES white paper, QM14





- **in-medium modifications to ρ expected to depend on total baryon density**
- **almost constant baryon density from 20-200GeV**
- **high-statistics BES-II**

Possible Charm Modifications at IMR

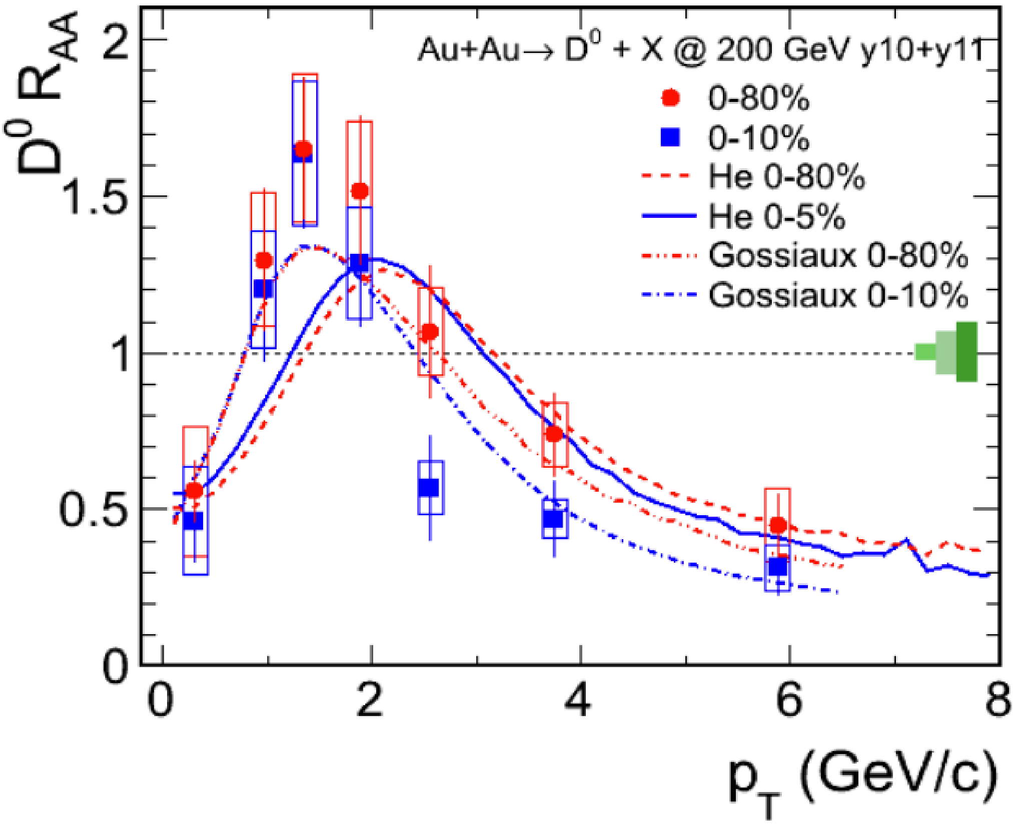


STAR, PRL 113 (2014)022301;

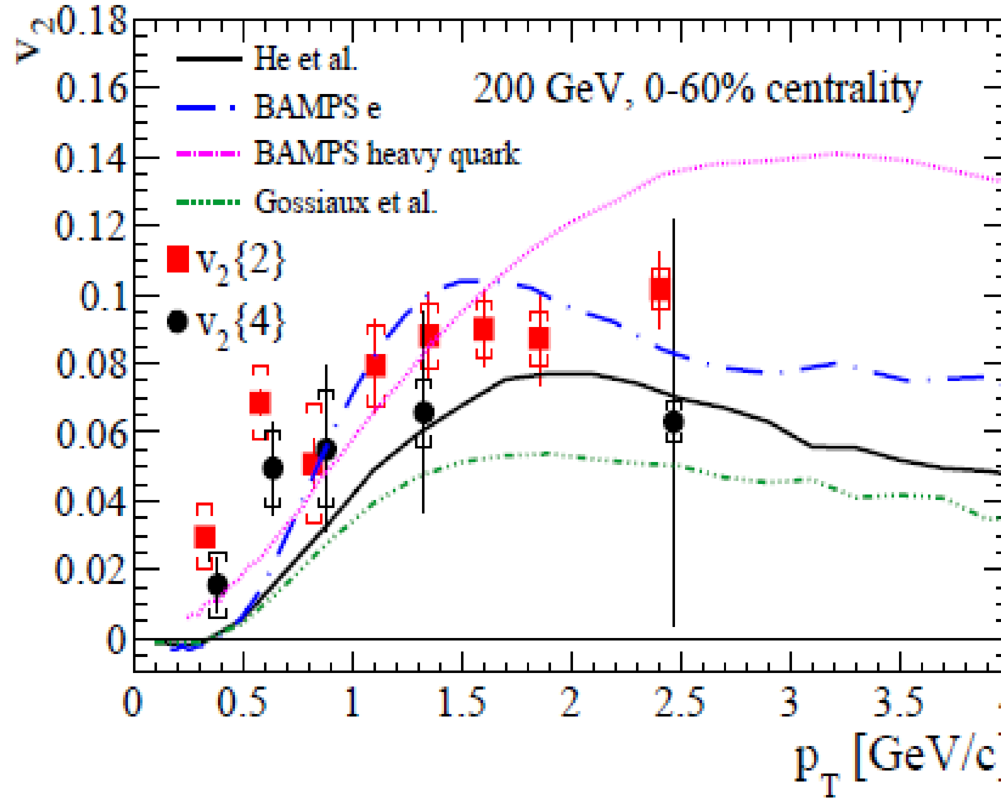
- **Central mass spectrum systematically steeper than minbias spectrum at IMR**
  - indicative of either charm modifications or other sources (thermal radiation?)

Other Evidences of Charm Modifications

STAR QM12, arXiv:1404.6185



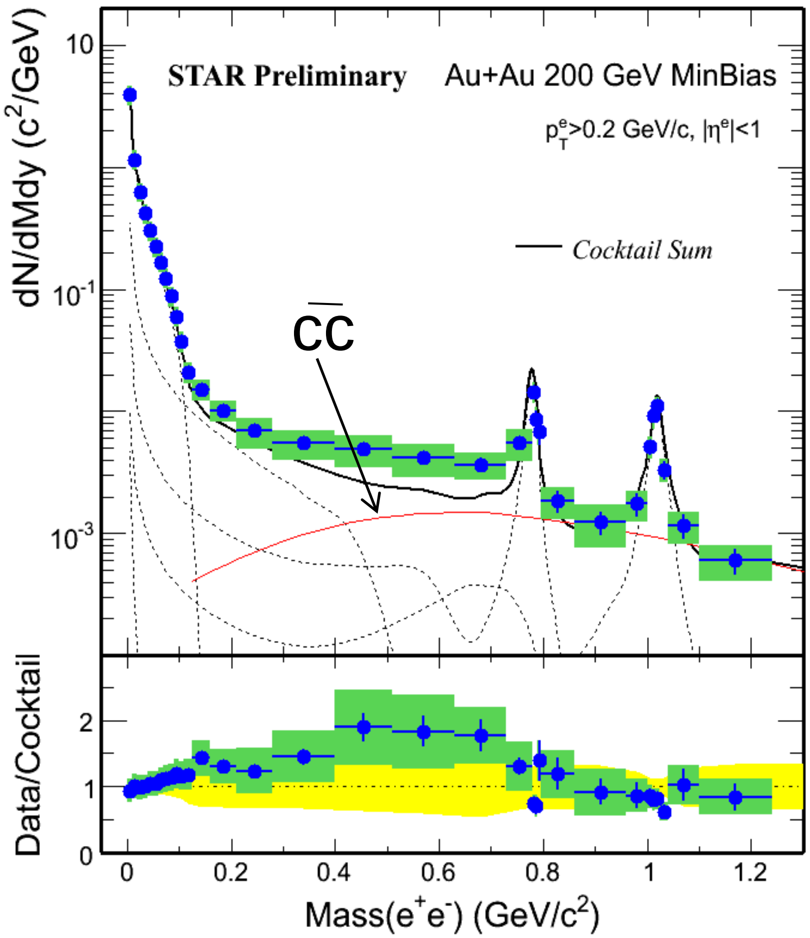
arXiv: 1405.6348

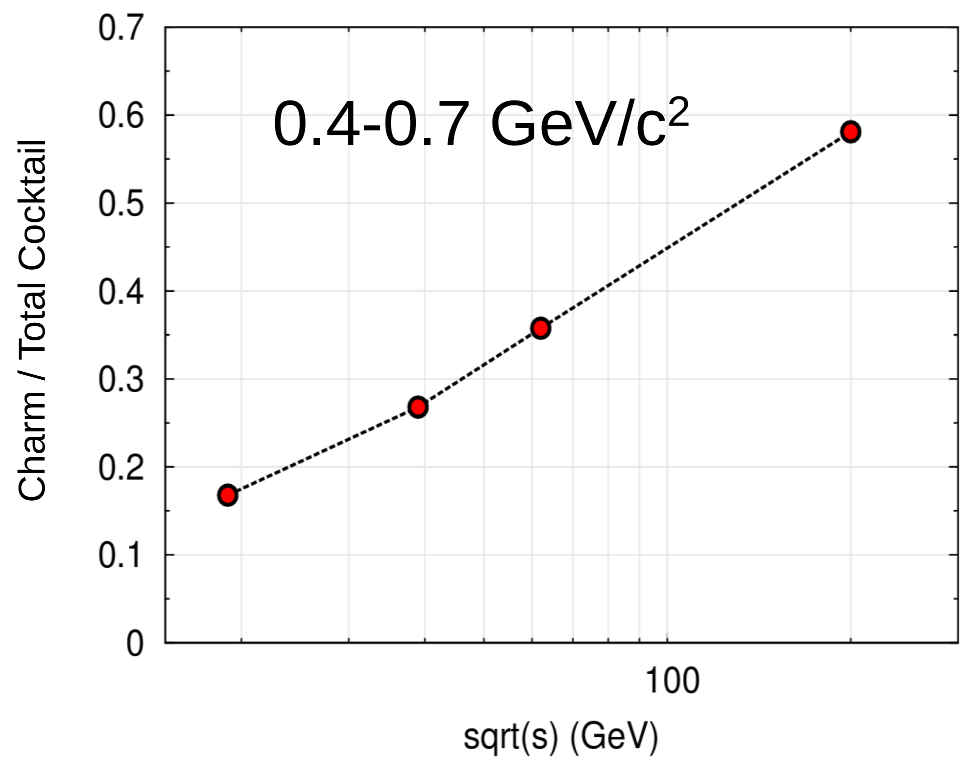


- **"bump" structure in low p_T D^0 R_{AA}**
- **Finite non-photonic electron v_2 at low p_T , and R_{AA} mesurements**

Significant charm-medium interactions in Au+Au collisions

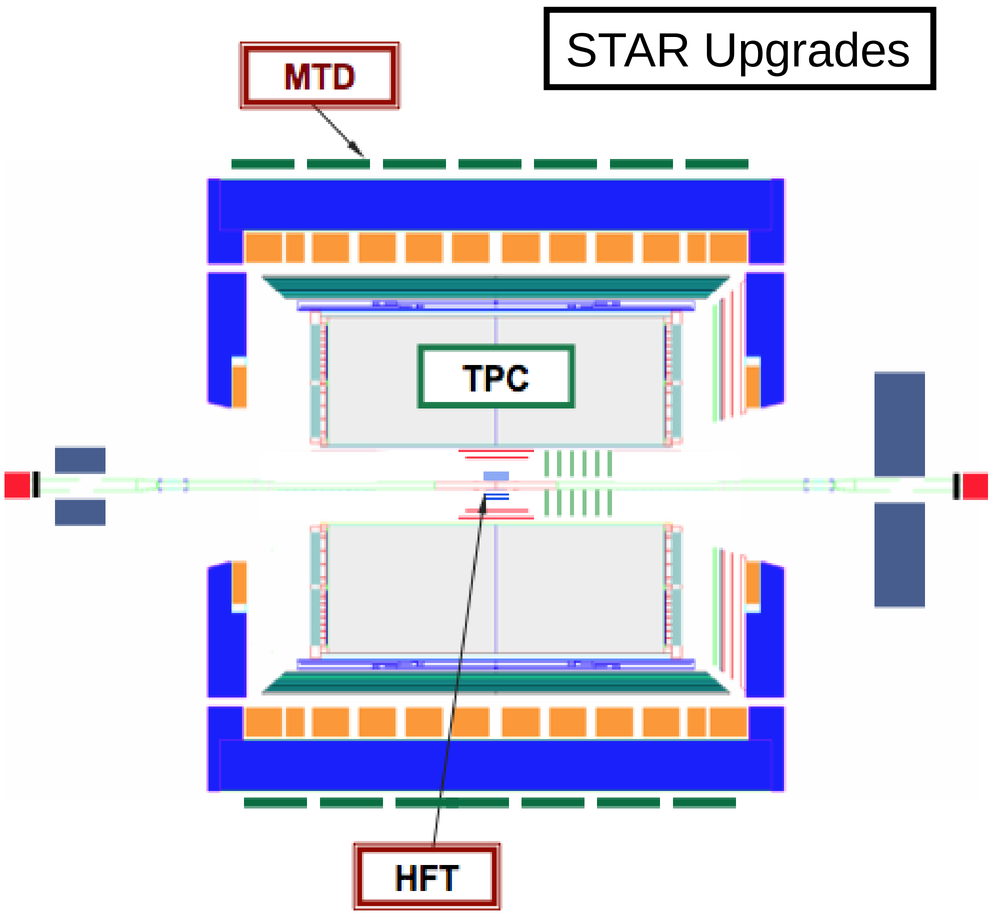
Importance of Charm at High Energy Collisions

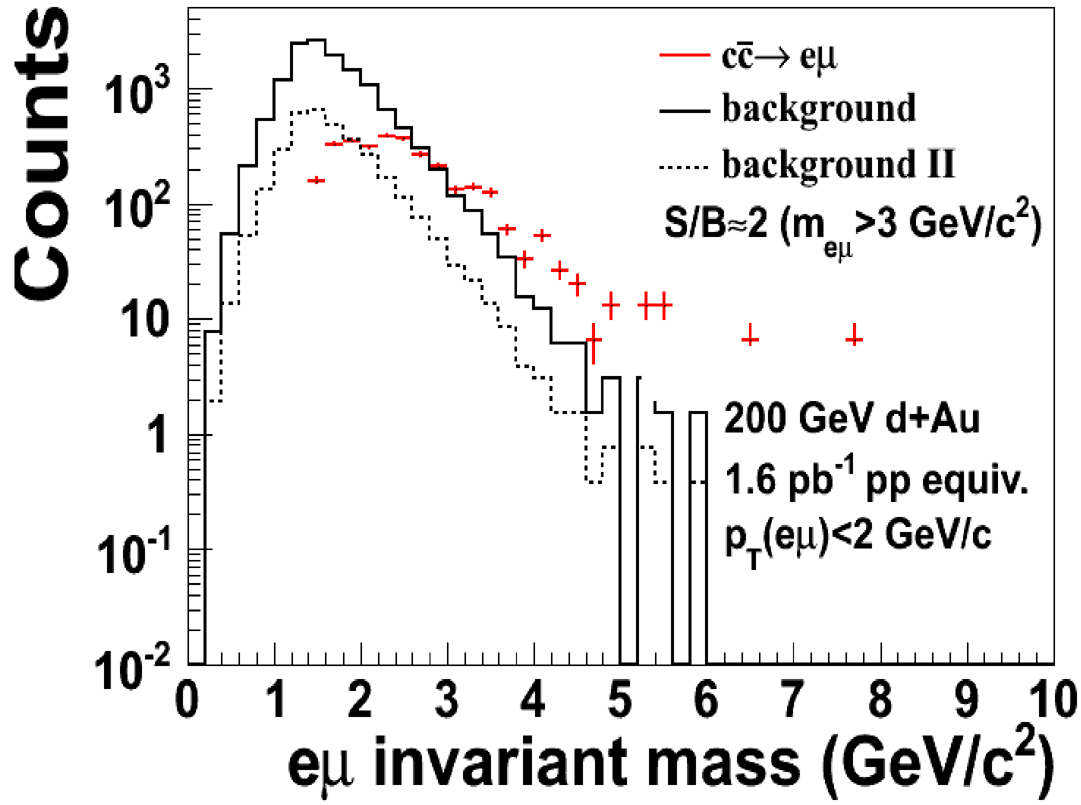




- **Correlated charm component is important in both IMR and LMR region in high energy HI collisions**
- **Systematic measurements of energy dependence**
  - – onset of QGP thermal radiation

Measure Correlated Charms





L. Ruan et al., JPG 36 (2009) 095001

HFT - topological separation of charm decay electrons from prompt
MTD - unique measurement of e-μ correlation – clean to D-D correlation
HFT+MTD help to measure the charm correlation directly.: D-D, e-D, μ-D, e-μ

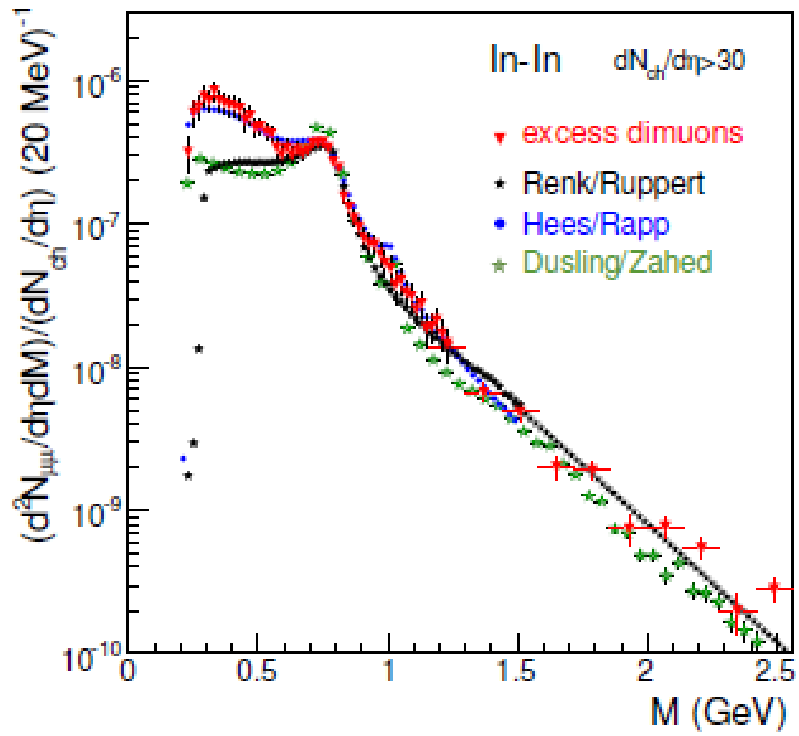
Quantify Thermal Dilepton Properties

Thermal dileptons at IMR (1.1 < M < 3. GeV/c²)

(1) Polarization (angular distribution) to probe the degree of thermalization

$$d\sigma / d\cos\theta \propto 1 + \alpha\cos^2\theta$$ ***E. Shuryak, 1203.1012***

Initial Drell-Yan, fully polarized $\alpha=1$
Completely thermalized, isotrop $\alpha=0$



(2) Partonic or Hadronic thermal source – Elliptic flow

$q\bar{q} \rightarrow l^+ l^-$ $v_2(ll) = 2v_2(q)$

$\pi\pi \rightarrow l^+ l^-$ $v_2(ll) = 2v_2(p) = 4v_2(q)$

Cross section, v_2, α (M, p_T)

At 2016, RHIC II projected L ~ 20 nb^{-1} @ 200 GeV
STAR recorded mb-equivalent events ~ 84 B (60%)
assuming 100% triggering efficiency, 400 MeV/c² bin, σ_{v2}= 1%, σ_α= 5%

Summary and Outlook

➢Low mass region:

> Enhancement in Au + Au collisions compared to the cocktail

> consistent with vector meson in-medium modification calculation

➢Intermediate mass region:

> need more precise measurement to constrain charm and QGP thermal radiation contributions,

➢RHIC (BES) - systematic measurements

> LMR enhancement vs. total baryon density.

> search the onset of sQGP thermal radiation and CP, need more statistics.

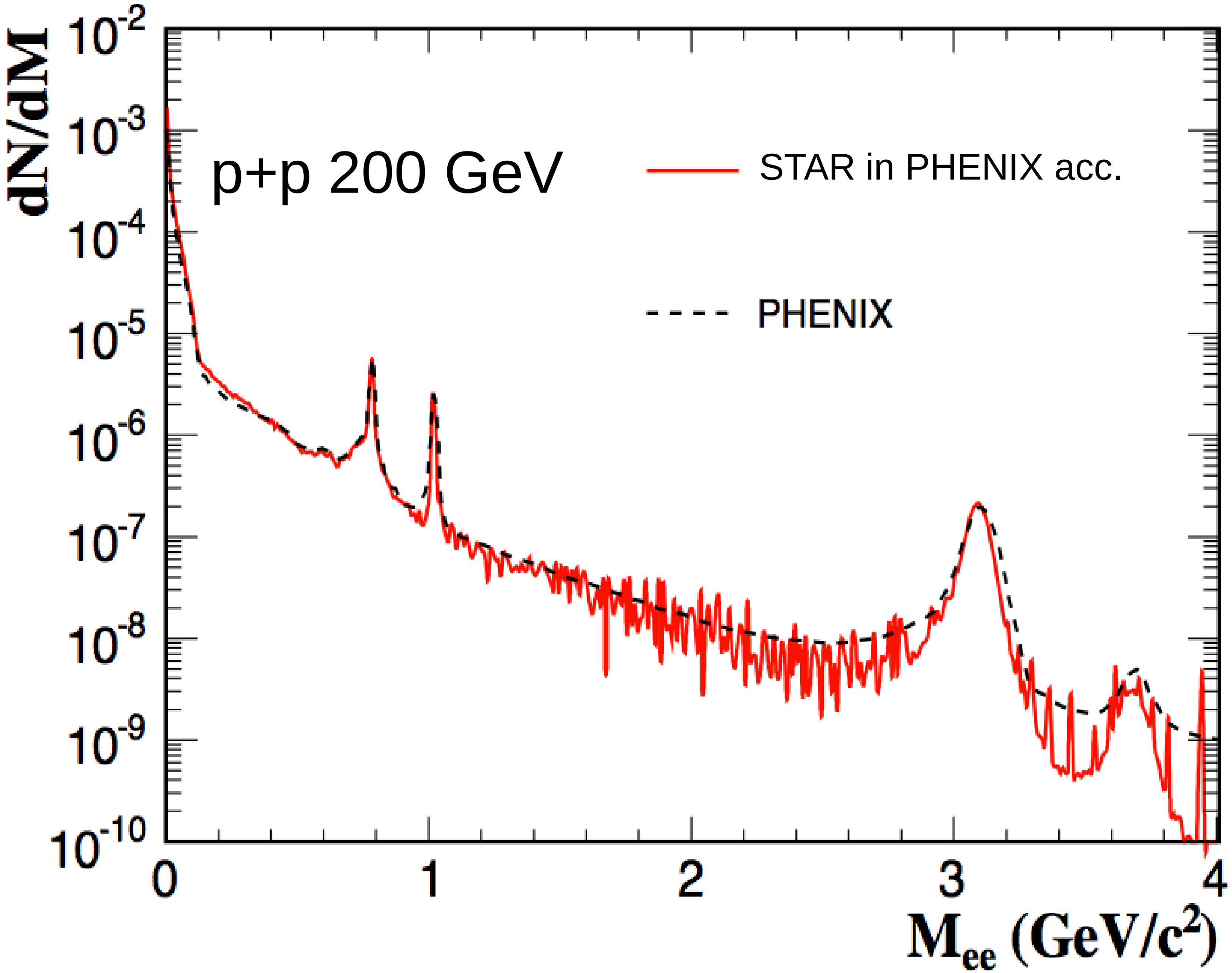
Outlook:

> STAR Heavy Flavor Tracker and Muon Telescope Detector upgrades, charm contribution! (D meson, eμ …)

> RHIC high luminosity and BES-II

BACKUP

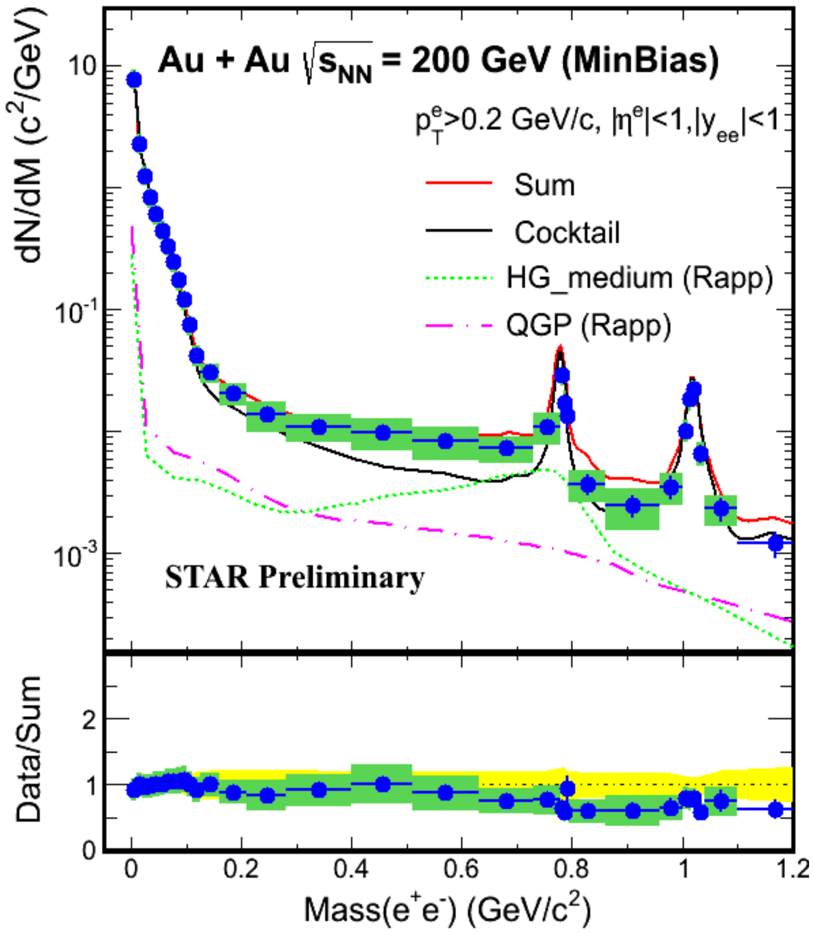
Cocktail Comparison

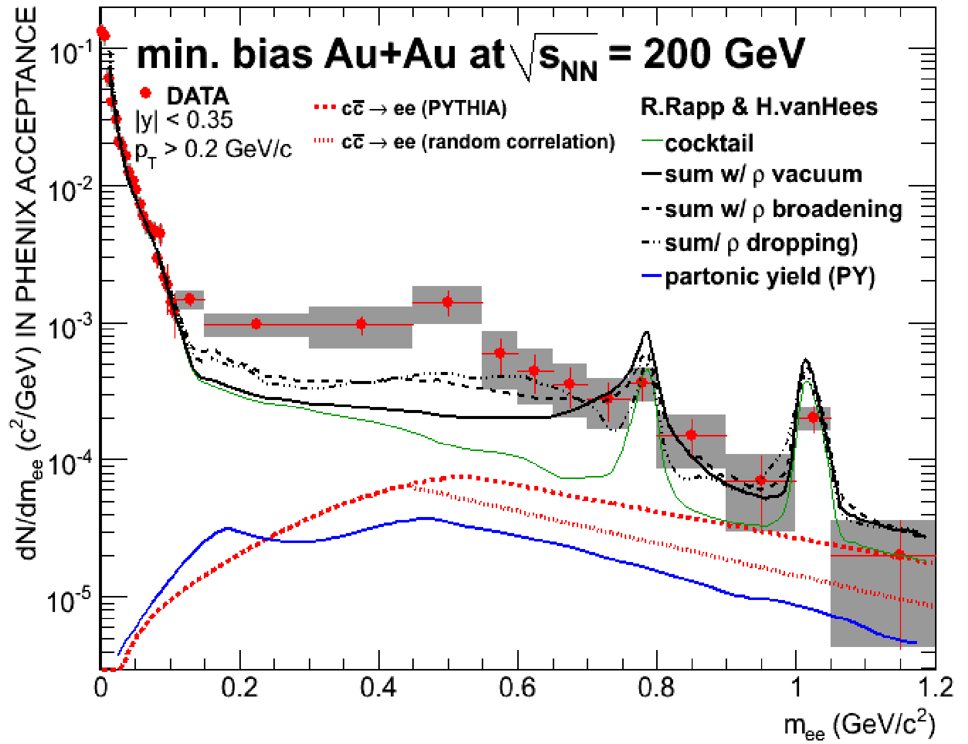


Different generators with the same detector acceptance give consistent cocktails

- some small differences due to decay form factors and detector resolutions

Comparison on Low Mass Enhancement



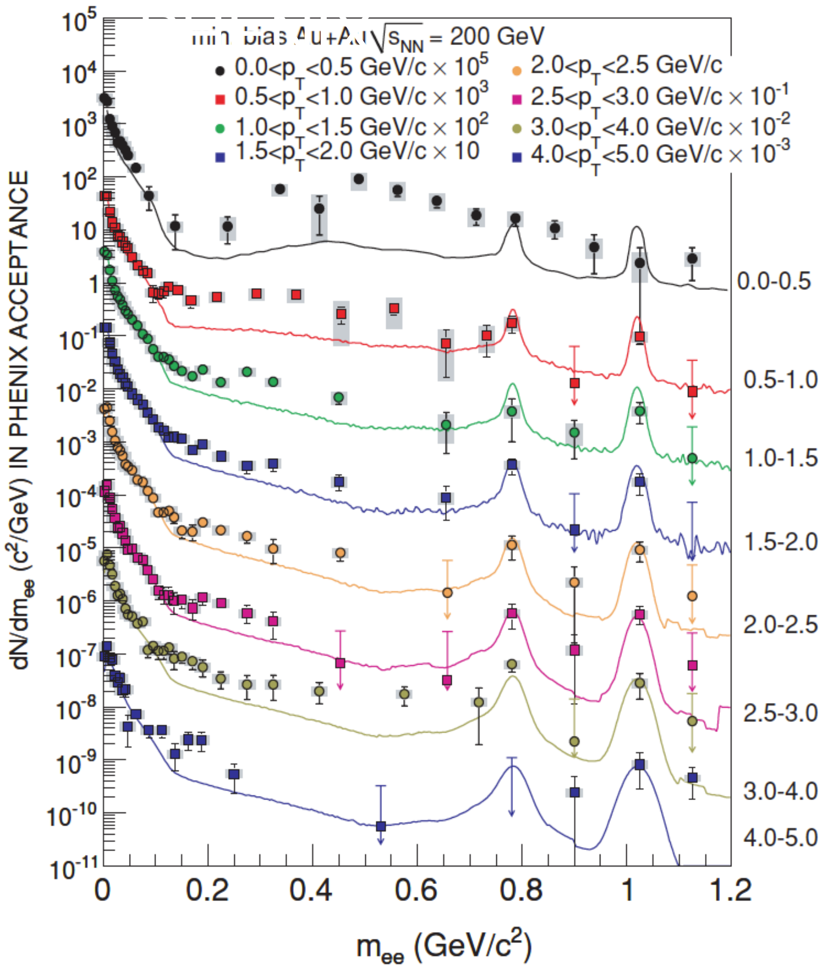


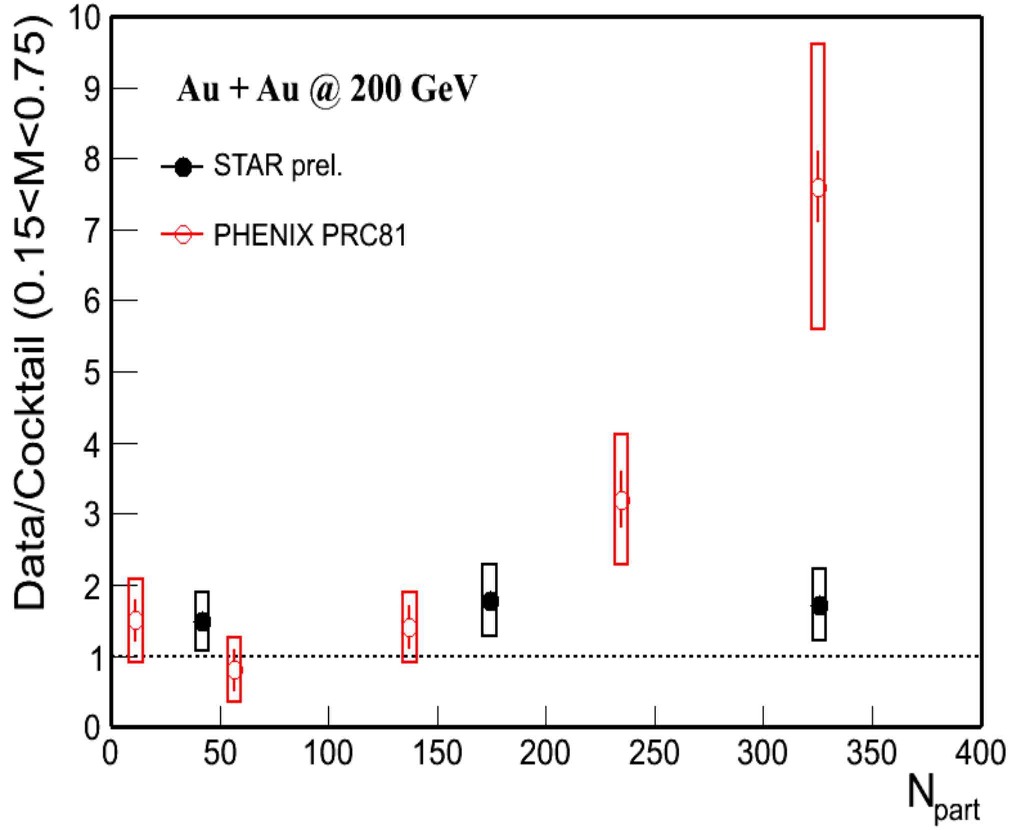
PHENIX PRC 81 (2010) 034911; STAR QM11

Enhancement factor in $0.15<M_{ee}<0.75$ Gev/c^2

	Minbias (value ± stat ± sys)	Central (value ± stat ± sys)
STAR	**1.53 ± 0.07 ± 0.41 (w/o ρ)** **1.40 ± 0.06 ± 0.38 (w/ ρ)**	**1.72 ± 0.10 ± 0.50 (w/o ρ)** **1.54 ± 0.09 ± 0.45 (w/ ρ)**
PHENIX	**4.7 ± 0.4 ± 1.5**	**7.6 ± 0.5 ± 1.3**
Difference	**2.0 σ**	**4.2 σ**

Centrality / p_T dependence





PHENIX PRC 81 (2010) 034911; STAR QM12

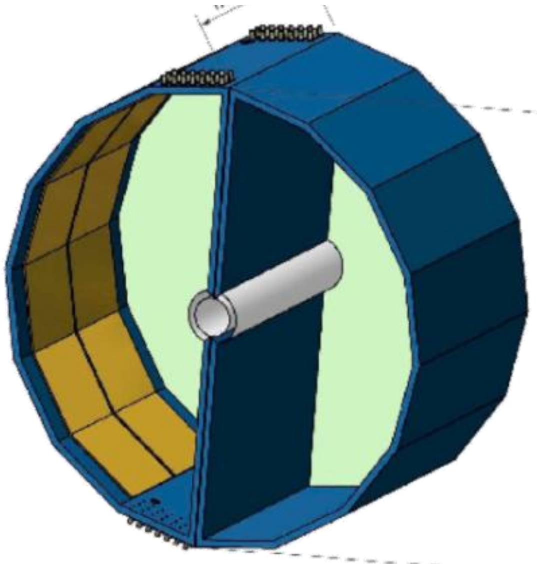
Enhancement factor (data/cocktail):

- PHENIX: Large enhancement appears in low p_T and central collisions

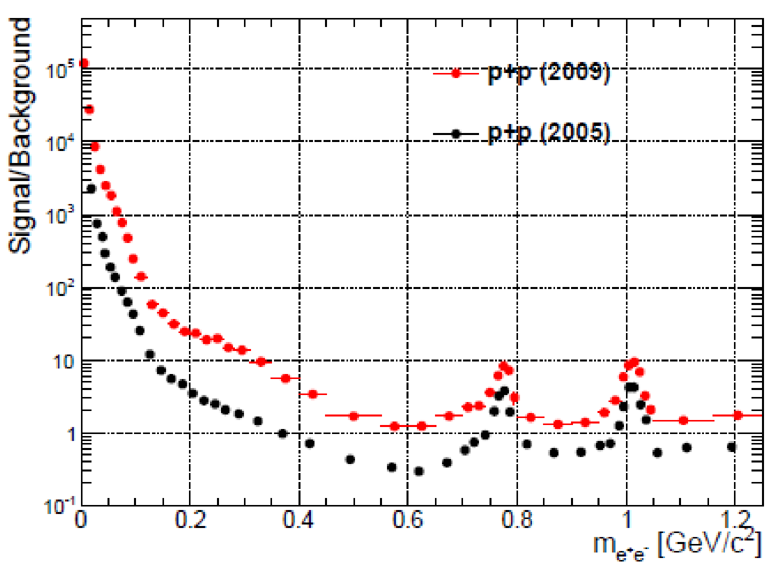
- STAR: Mild centrality and p_T dependence

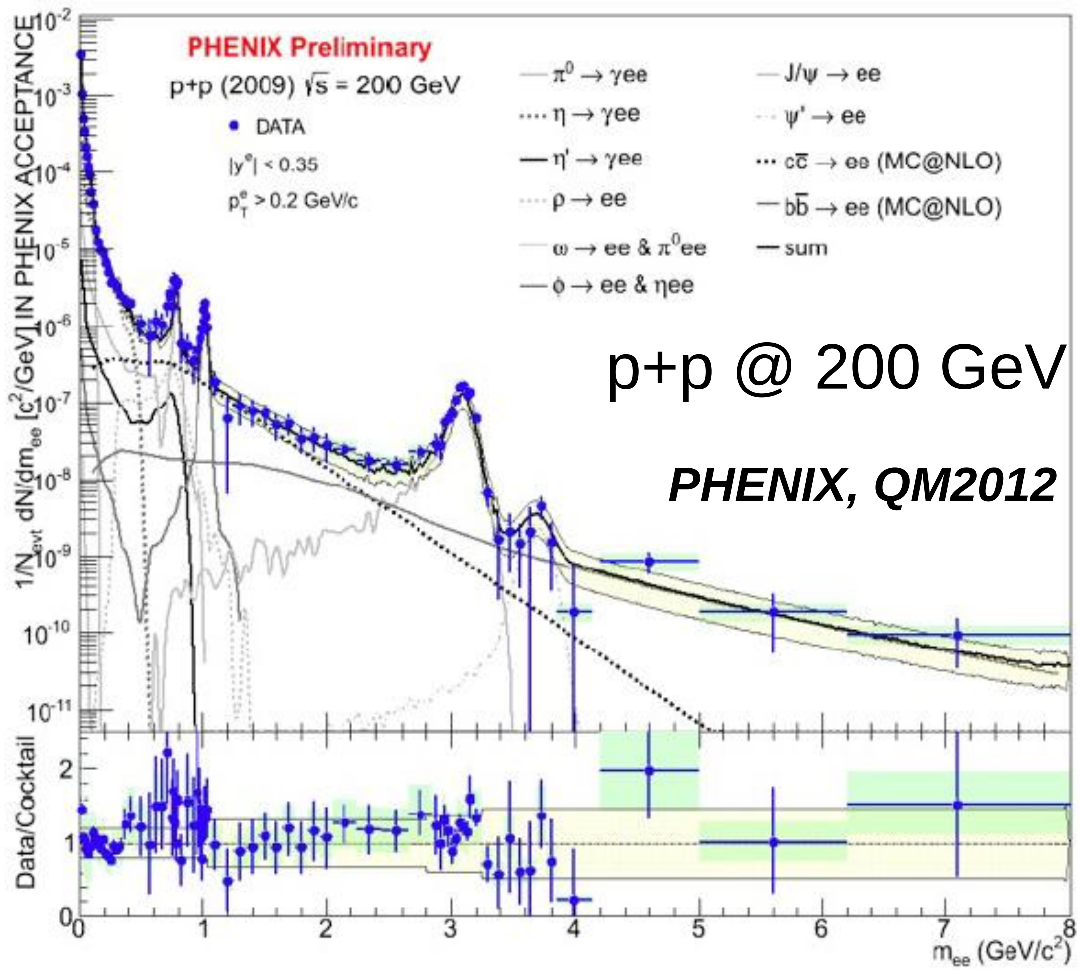
Hadron Blind Detector at PHENIX

- Goal: improve S/B by rejecting conversions and π^0 Dalitz decays
- Installed to take data in p+p 200 GeV (2009) and Au+Au 200 GeV (2010)



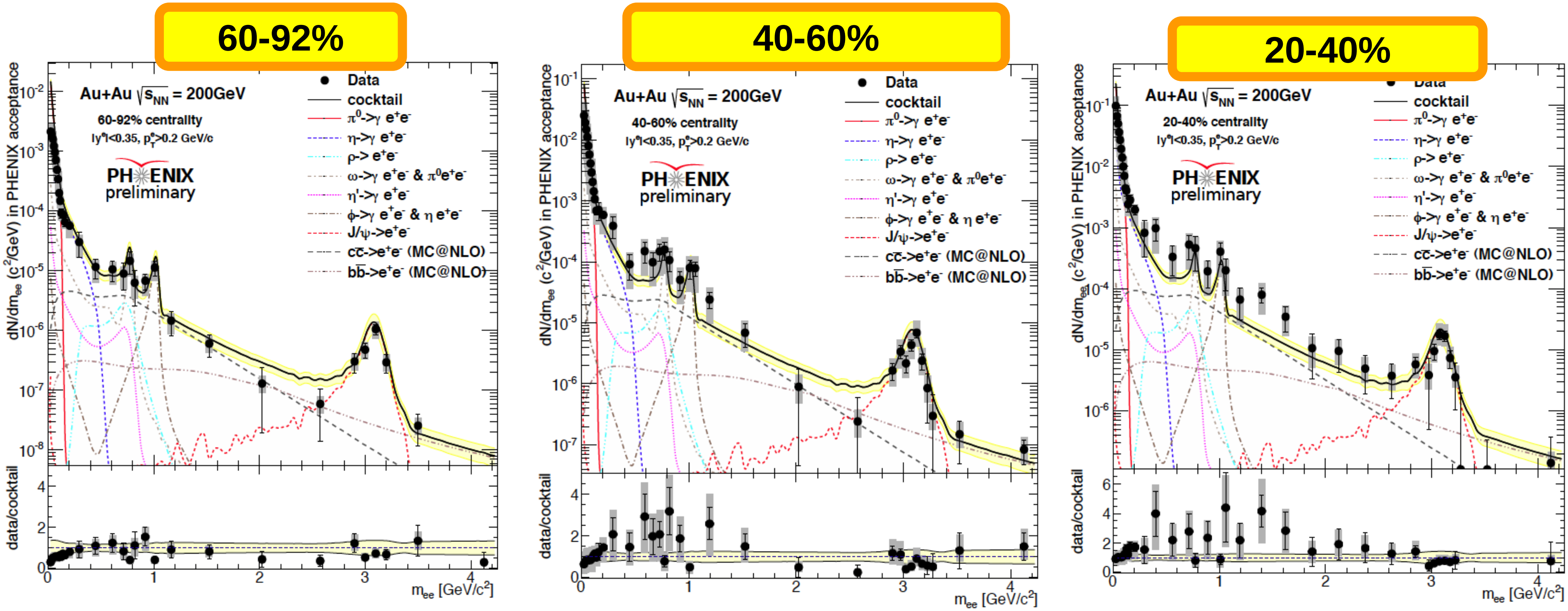
NIM A646, 35 (2011)





Dielectron with HBD in Au+Au Collisions

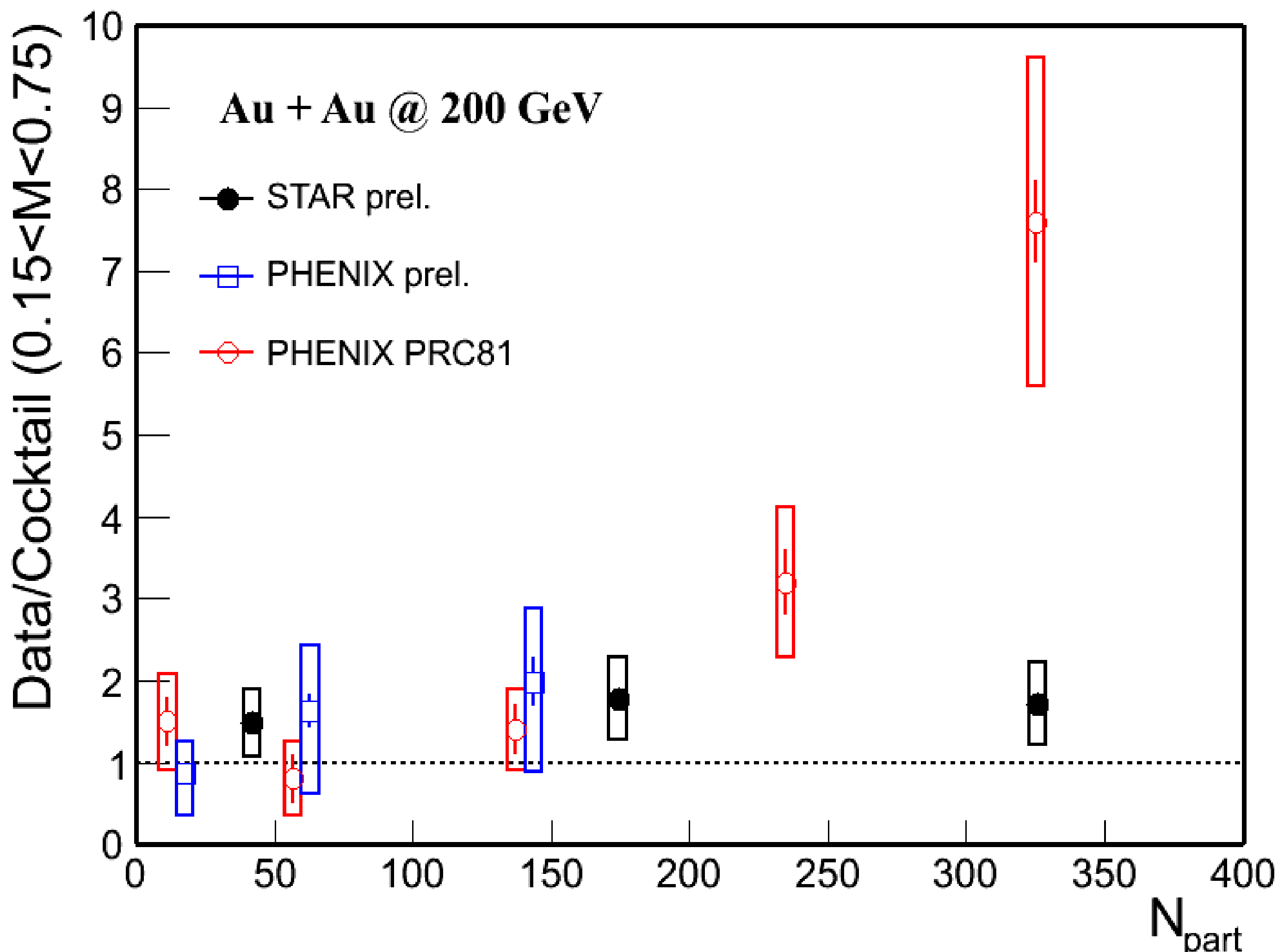
Au+Au 200 GeV



PHENIX, QM12

Preliminary results report in 20-40%, 40-60%, 60-92% centrality bins

LMR enhancement with PHENIX HBD



HBD result in 20-92% centrality bins consistent with previous PHENIX result and also STAR preliminary result

- Looking forward to the HBD result in 0-20% centrality bin